Inventory of Potential Irrigation Development in Central North Dakota

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Water Resources
Investigations No. 62

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ACKNOWLEDGMENT

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CORRECTION

(October 12, 1995)

This report copy contains corrections made in Table ES-1 (page ES-3) , and on pages ES-1, ES-6, ES-9, and ES-10 of the Executive Summary. Errors were all based on misplaced numbers in Table ES-1. Corrections result in a change of estimated total potential irrigable acreage (column 7 of Table ES-1) from 307,500 acres to 311,500 acres; a change of approximate current water permits (column 8 of Table ES-1) from 94,107 acres to 116,500 acres; and a change of approximate additional development from 208,000 acres to 195,500 acres. These errors have also been corrected in the text of the Executive Summary. The errors do not change the general results summarized in the Executive Summary. These results are: a minimum of about 300,000 acres of irrigation appear to be feasible in eighteen counties of central North Dakota. Of these, about one third (100,000 acres) are currently under irrigation, and about two thirds (200,000 acres) might still be developed. The errors corrected do not affect the main body of the report. All corrections are in the Executive Summary.

EXECUTIVE SUMMARY

The purpose of this report is to estimate potentially irrigable acreage for eighteen counties in central North Dakota. The counties included are shown on Figure ES-1, and listed on Table ES-1. In order to understand the estimates derived for each of the county reports, it is important that the reader have some understanding of the factors considered in estimation. While this brief summary cannot fully explain the significance of all of the assumptions and technical procedures involved with the estimates derived in this study (please refer to Introduction and Methods sections), it is hoped that it will provide a reasonably concise and simple explanation of the nature of the study that will assist the reader in using it with common sense.

Irrigation development is far from a simple matter. The two main resource limitations are those of suitable soil, and suitable water. Availability of suitable land is dependent on soil texture, slope, surface drainage, internal drainage, water table depth, sodicity, salt content and salt buffering capacity, organic matter and resistance to slaking, pH, and other agronomic properties. Availability of suitable water is dependent on finding water supplies that are of appropriate quality (low salt, low sodium, low selenium and boron) and which are capable of sustained pumping at rates sufficient for irrigation. Other factors, including design limitations, cost, alternative land uses, landowner preferences, environmental concerns, and political impediments also strongly effect the irrigation development process. Design, cost, and political considerations, for example, generally place limits on the distance of water transport and require that available soil and available water be in reasonably close proximity. Each of these factors can have a major affect on the cost and feasibility of development.

Because of the complexity of factors affecting irrigation development, achieving a realistic estimate of potential irrigation development is difficult. Based on soil suitability assessment alone, a study by North Dakota State University (NDSU) has indicated that there are about eight and a half million acres of land which might be irrigated in the eighteen counties of this study (Omodt 1982). About six million acres of this total are comprised of soils that would have some limitations, such as slow internal drainage, high water table, excessive surface slope, poor surface drainage, salt problems, or sodium problems. The other two and a half million acres would be suitable for irrigation development without significant management problems, provided suitable water is available.

The amount of land that would be practically irrigable is much less than the 8.5 million acre estimate based on soil suitability alone. The estimate of potentially irrigable acres derived in this study for central North Dakota is about 300,000 acres (311,500 acres), or about three times the current total acreage of water permitted for irrigation (116,500 acres, Table ES-1). The 311,500-acre estimate of

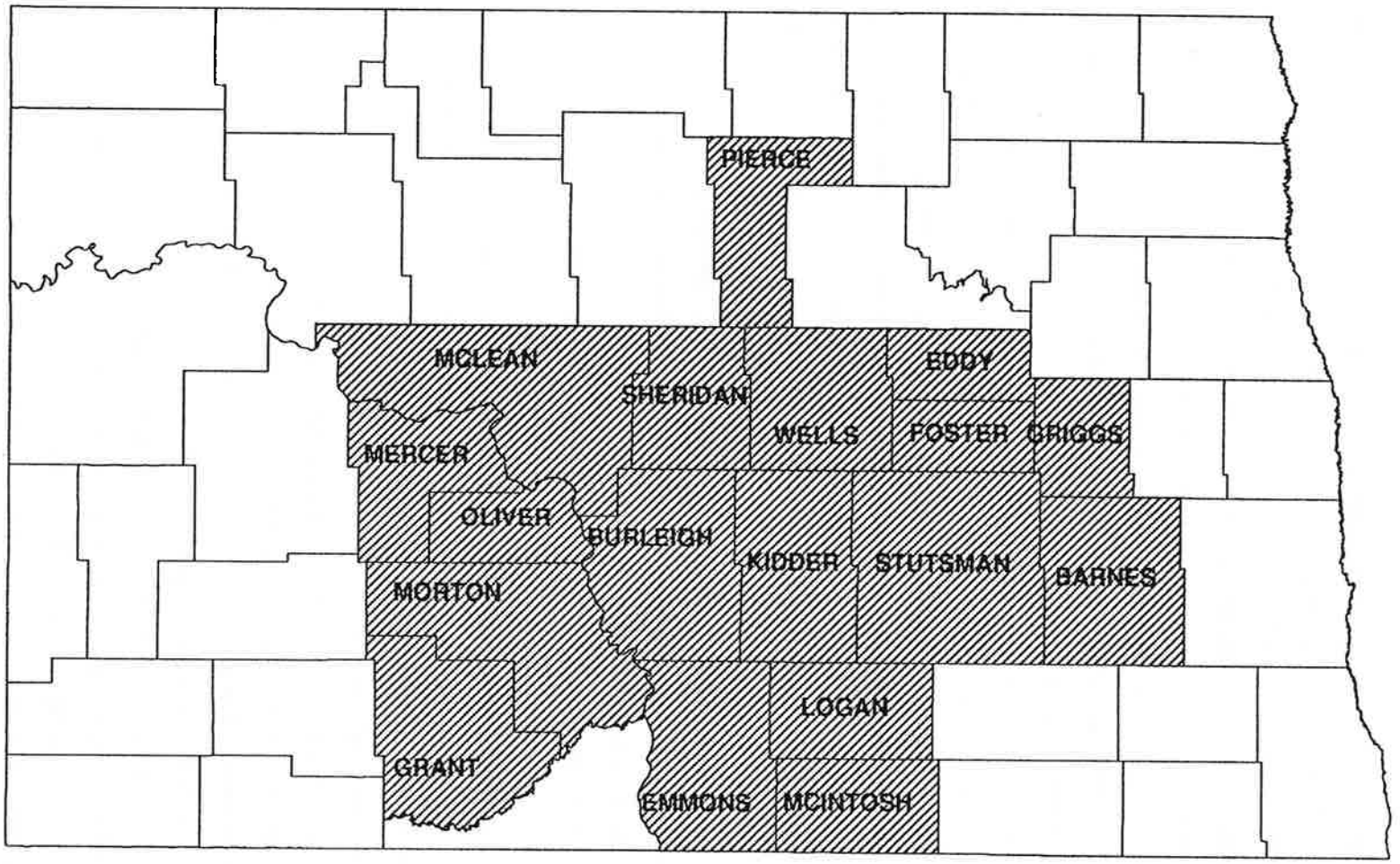

Figure ES-1. Map of eighteen central North Dakota Counties included in the irrigation development feasibility report. Included are Barnes, Burleigh, Emmons, Foster, Grant, Griggs, Kidder, Logan, McIntosh, McLean, Mercer, Morton, Oliver, Pierce, Sheridan, Stutsman, and Wells Counties.

Table ES-1. Summary of land and water resources available for irrigation in central North Dakota.

(1) County	(2) Irrigable Land Overlying Aquifers (acres)	(3) Adjusted Irrigable Land Overlying Aquifers (acres)	(4) Amount of Irrigation Development Based On Water Supply Limitations (acres))	(5) Approximate Potential Irrigation Development Based on Most Limiting Factor (acres)	(6) Approximate Potential Irrigation Development Using Surface Water (acres)	(7) Total Potential Irrigation Development (acres)	(8) Approximate Current Water Permits (5/20/95)) (acres))	(9) Approximate Additional Development (acres)	(10) Comment (acres)
Barnes	24,000	12,000	14,500	8,500	500	9,000	2,500	6,500	
Burleigh	34,000	17,000	6,000	6,000	60,000	65,000*	17,000	48,000	
Emmons	13,000	6,500	7,000	6,000	39,000	44,500*	11,000	33,500	
Eddy	20,500	10,000	11,000	4,000	0	4,000	2,500	1,500	
Foster	33,000	16,500	12,000	10,500	0	10,500	6,500	4,000	
Grant / Morton	9,000	4,500	3,500	2,000	23,000	31,000*	2,000 / 5,500 plus 7,000 USBR Permit 250B (total 14,500)	16,500	May be some difficulty in locating ground-water of good quality
Griggs	32,000	16,000	8,500	8,000	0	8,000	7,500*	500	May be as much as double projected amount
Kidder	52,000	26,000	51,000	26,000	0	26,000	11,500	14,500	May be as much as double projected amount
Logan	13,000	6,500	13,500	6,500	0	6,500	2,500	4,000	May be as much as double projected amount
McIntosh	36,000	18,000	12,000	7,000	0	7,000	500	6,500	May be as much as double projected amount
McLean	65,000	32,500	17,500	17,500	35,500	51,000	14,500	36,500	As many as 14,000 additional acres may be irrigable
Mercer	32,000	16,000	9,500	8,000	7,000	14,000*	9,000	5,000	
Morton	26,000	13,500	10,500	9,000	Combined with Grant Cty	Combined with Grant Cty	Combined with Grant Cty	Combined with Grant Cty	
Oliver	12,500	6,000	3,500	3,500	6,500	8,500*	7,000	1,500	
Pierce	14,500	7,000	5,000	4,500	0	4,500	1,500	3,000	
Sheridan	18,000	9,000	10,000	7,500	1,500	9,000	500	8,500	Some additional irrigation may be possible
Stutsman	63,000	31,500	18,500	7,000	7,000	7,000	7,500	0 †	Some possible additional irrigation, from limited mining of Spiritwood aquifer
Wells	24,000	12,000	6,500	6,000	0	6,000	500	5,500	
Total	521,500	260,500	220,000	147,500	180,000	311,500*	116,500	195,500 †	

* adjusted for overlap of ground water and surface-water irrigation lands.

† column 9 does not equal the difference of columns 7 and 8 because water permit acreage estimates exceed estimates of potential irrigation acreage for Stutsman County.

land for potential irrigation development includes land currently permitted for irrigation. Additional water permits would total about 200,000 acres (195,500 acres). Given the conservative bias of this estimate, and potential error in estimation, the actual total of all irrigated acreage for the eighteen counties may be somewhat higher, but would likely not exceed 500,000 acres, even with more relaxed criteria. Some further clarification of the meaning of these numbers is necessary.

Criteria for Determining Potentiallly Irrigable Land

The 300,000-acre potential irrigation acreage estimate in this study consists of land that is likely irrigable without excessive management, cost, or political impediments. It was the intention of the compilers of this study that it should provide an estimate that is on the "conservative" or lower end of a reasonable range of values. The reader is encouraged to read the Introduction and Methods section of this report for a full description of methods used in computation. However, a brief description of the assumptions made in computation, and a brief assessment of their potential effect on final estimates is provided in this summary.

Irrigable land estimates in this report consist of soils of irrigable or conditionally irrigable classification that do not exceed 3 % slope, and for which substantial surface irrigation or tile drainage are not required. Irrigable land must also be in close proximity to supplies of suitable water. The proximity requirement for ground water is that the irrigable land must directly overlie the aquifer (Table ES-1, column 2). The proximity requirement for surface water is that irrigation must be possible within five miles of the surface water source, that static lift for transport of water cannot exceed 260 feet, and that maximum distance of irrigable land not be more than seven to ten miles from the source, depending on the size of the tract (Table ES-1, column 6). These limitations are modified slightly in some circumstances, but are generally consistent throughout the study. Finally, a conservative "contingency factor" of 1/2 was applied to all land mapped as suitable for irrigation. The purpose of the contingency factor is to account for errors in estimation and landowner preference, and to provide a conservative bias for the results (Table ES-1, column 3).

Water availability limitations are also included. Water must be of suitable quality for irrigation. Suitable quality is that having electrical conductivity of less than 1,500 µs/cm, sodium adsorption ration of less than 6, and boron content of less than 2 mg/L. There were no waters having large selenium content in this study.

Surface waters included as potential supplies must be substantial, and provide a reasonably consistent annual supply. Surface water sources included were the Missouri River, Lake Sakakawea, Lake Audubon, the McClusky Canal, the Heart River, the Cannonball River, and the Knife River. For each of these rivers, potential irrigation was estimated based on summer flows, allowing for a reasonable base flow after withdrawal (Table ES-1, column 6). Fourth order streams, and smaller third

order streams (direct tributaries of the Missouri River) were excluded from consideration because of their ephemeral nature. The James and Sheyenne Rivers were included in analysis, but were found to be effectively negligible potential sources in the counties studied because of prior allocations in counties outside of the study area. Small lakes and potholes were excluded as potential water sources because of their ephemeral nature, and because of potential environmental concerns.

Ground water supplies are estimated based on aquifer maps from County Ground Water Studies, and supplemented by other more recent sources. The criterion of water availability was "sustainable yield", based on estimated annual recharge of the aquifers (Table ES-1, column 4).

Final estimates of land available for potential irrigation development in each county were made by tabulating the acreage estimated for the most limiting resource (land or water) for each aquifer, and summing the acreage for all aquifers in the county (Table ES-1, column 5). This total was added to estimated irrigation development using surface water and adjusted for overlapping development from ground water and surface water (Table ES-1, column 7).

The approximate 300,000 acre estimate for potential irrigation is based on all of the assumptions made above. If less restrictive criteria than those given above are allowed, then more land may be irrigable. Relaxation of each restriction, however, adds to the difficulty and cost of development, and decreases the level of flexibility of management and operation. Even with relaxation of the above restrictions, however, it is doubtful that the total of irrigable land in these eighteen counties would far exceed a half million acres under optimal conditions. Reasons for these interpretations will be given in the following discussion.

Affect of Soil Suitability Assumptions on Irrigation Development Estimates

This study has used a more limited subset of soils classified as irrigable and conditionally irrigable in North Dakota by the USDA-SCS (1977). Slope is limited to 3%, surface and tile drainage requirements are excluded. There is also a 1/2 contingency factor to account for potential error of estimation and landowner preference.

One reviewer of this report has pointed out that 3% land slope limit is quite conservative, and that land slopes of up to 6% may be irrigable. This would add a substantial number of irrigable acres in some counties. However, the same reviewer points out that use of low pressure irrigation systems on large fields might not be possible on the larger slopes, so that management flexibility is decreased.

There are some soils that may be irrigable with appropriate surface and subsurface drainage which have been excluded from this study. These have been excluded because of the expense and political complexity of large-scale drainage projects. Under the current irrigable land assessment criteria, drainage on a minor scale will be required. Soil survey methods do not exclude limited acreage of wet soil within areas mapped to well-drained soils. However, if major mapped soil units of

poorly drained soil are included, large-scale infrastructure development and the formation of drainage districts would be required. Moreover, outlets for the water would be needed, and assurance that contaminants are not reaching major waterways would be required. Such complications do not prohibit irrigation. But they do add to the time and expense of project development. As with the slope criteria, more land overlying aquifers or near surface-water sources may be irrigable if the additional effort, expense, and loss of flexibility of management resulting from large-scale land drainage is not prohibitive.

In Kidder and McLean Counties an additional requirement that irrigable land units be a quarter section or larger is also limiting. One reviewer has suggested that an 80 acre lower limit might be more realistic. Use of an 80 acre lower limit would likely have increased the amount of land having soil suitable for irrigation by a few thousand acres in Kidder County. Even lower limits might increase the amount of potentially irrigable land still more.

The 1/2 contingency factor used for estimation of irrigable land (column 3, Table ES-1) is an arbitrary adjustment to allow for potential error, and to insure a somewhat conservative bias. Without the 1/2 contingency factor final estimates of irrigable soil would be doubled (column 2 of Table ES-1). However, even if we choose to ignore all of the above limitations, the final estimates of total irrigable land will not be unduly affected. This is because in most counties the main limiting factor is not irrigable soil, but water supply. For each county estimated potentially irrigable acreage is determined by the most limiting factor (soil or water) overlying each aquifer. From table ES-1, comparison of column (3) and column (4) indicates that land is limiting only in Barnes, Kidder, and Logan Counties. These would be the only counties where removal of the 1/2 contingency factor and other soil-related irrigation development restrictions would have a significant effect on estimates of potentially irrigable acreage. In Kidder and Logan Counties total irrigable acreage might be as much as doubled (from 26,000 and 6,500 acres, to 52,000 and 13,000 acres respectively). Affects of liberalizing soil criteria and removal of the 1/2 contingency factor would thus have a net overall effect of increasing the total estimate of land overlying aquifers for potential irrigation development from about 311,500 acres to about 342,000 acres.

If the contingency factor (1/2) were removed from the estimates of irrigable land using surface-water sources, (column 6, Table ES-1) more than 100,000 acres may be added to the overall estimate. With all of these limitations removed, however, the total amount of land estimated to be suitable for irrigation development in the 18 counties designated for this study would be unlikely to exceed one-half million acres.

Affect of Water Supply Assumptions on Irrigation Development Estimates

Assumptions limiting water supply are water quality requirements, and the use of sustainable yield criteria for estimating the amount of water available from aquifers. In the case of surface water, the limitations of distance from the source are likely also limiting.

The water quality limitations (1,500 µs/cm electrical conductivity, 6 SAR, and 2 Boron) are conservative, but appropriate. Although there are some crops and soils that might tolerate more saline or sodic water, there is a tendency in some cases for water quality to degrade somewhat after extended pumping, because of drawing water from lower quality areas of the aquifer to the well. For this reason, the initial water quality criteria should include a tolerance margin for natural degradation. There is some possibility that these criteria might be relaxed for some soils. However, detailed studies of salinity and sodicity effects on individual soil series would have to be determined. Current estimates are based on standards published from general research by the U.S. Salinity Laboratory Staff (1954). Recently Saskatchewan has completed research to locally adjust salinity and sodicity indices for irrigation water. Such research would be beneficial for North Dakota.

The sustainable yield criterion used in this study is based on estimates of recharge for each aquifer. For some large aquifers, like the Spiritwood and New Rockford aquifers, substantial increased irrigation might be possible on the basis of limited mining. In large aquifers, a limited loss of stored water can often occur without affecting water availability and use. Because of the size of the aquifers, such mining could be practiced for extended periods of time, without depleting water. However, in some smaller aquifers the effect of mining could be immediate and dramatic. Such cases would have to be considered carefully on a case by case basis, and would have to be carefully monitored. Some counties where limited mining of water might be considered are noted in column 10 of Table ES-1. Where limited mining may be feasible, it is discussed in the individual county report.

The condition of proximity to the surface water source, and the static lift limitation are cost determined. If the cost of infrastructure were not limiting, there are substantial tracts of soils more than ten miles from the Missouri River that are suitable for irrigation. One example is Burleigh County where irrigable soils having few limitations are ample in the central part of the county (See the Burleigh County Report). If infrastructure costs were not prohibitive, the estimated 60,000 acres of potentially irrigable land using water from the Missouri River might be substantially increased.

Precision of Results

This analysis has been based on a large number of reasoned assumptions. Because each assumption has a random error associated with it, and because random error may be positive or negative, there is a tendency for errors to cancel when applied over large numbers of assumptions,

large land areas, or large times. In many studies, this results in increasing accuracy of prediction when applied over extensive units of time or area. As it pertains to this study, potential irrigation development from any individual aquifer or tract of land may be overestimated or underestimated. Precision will also likely vary with individual counties, or areas. **However, we believe that the overall estimates derived of about 300,000 acres of potential irrigation development in the eighteen counties studied, with a possible development not exceeding a half million acres under optimal and less restrictive conditions, is reasonably accurate.** While some might view this as a broad range (300,000 to 500,000 acres), it is a far more realistic number for actual development than the 8.5 million acres of total irrigable and conditionally irrigable soil estimated on the basis of soil alone, and the 2.5 million acre estimate of soils that are irrigable without limitation (Omodt 1982).

On a county level, the precision of this study undoubtedly varies. A single methodology has been applied to a large number of differing circumstances, with slight adjustments for local conditions. The advantage of this approach has been consistency of criteria, and an objective standard which minimizes the dangers of an excessively subjective assessment. However, the effects of assumptions made in this study vary with counties. State Water Commission managing hydrologists for each of the counties have reviewed reports for their counties. The authors of this report consider the comments of those managers who have researched and dealt with local water resource allocations to be a valuable "check" on this study. Most have considered the prospective estimates of water availability for irrigation to be within reason. Some have considered them to be slightly high, while others have considered them to be slightly low. Mitigating comments of managing hydrologists have been incorporated into the discussion of individual reports.

Two counties where a combination of factors may have led to a low estimate are Kidder County and Logan County. In most counties studied, water resources were most limiting. While suitable soil appears to be limiting in Barnes County, the difference between estimated suitable soil acreage and water-resouce limited acreage is not large. However, in Kidder and Logan Counties there is a large difference between estimated suitable soil and suitable water.

In both Kidder County and Logan County, estimated suitable water is nearly double estimated suitable soil. Under these circumstances the 1/2 contingency factor and the sustainable yield criteria have a large effect on acreage estimates for irrigation development. In fact, dispensing with the 1/2 contingency factor in suitable soil acreage estimates alone would nearly double potential development estimates to a maximum of 51,000 acres for Kidder County and 13,500 acres for Logan County, based on water availability estimates (Table ES-1, columns 2,3, and 4). Additional relaxation of assumptions made in soil suitability analysis (such as using an 80 acre rather than quarter section minimum field size) would not increase the estimated potential for irrigation over these limits because

water, not soil, would then be limiting. In Kidder County, because of the extensive size of the Kidder County aquifer complex there is also the potential for a few thousand additional acres of development from limited mining. **For Kidder County, the 26,000 acre estimate is thus likely to be very conservative. Under optimal conditions, irrigation development might double, or slightly exceed double this sum. For Logan County estimated acreage for potential irrigation development might also be as much as double the estimated amount.**

Environmental Concerns

In recent years there has been increasing concern over environmental issues such as endangered species and preservation of high priority wetlands. The criteria used in this study were purposely designed to avoid inclusion of lands where controversial or politically sensitive development might occur. Elimination of small lakes, potholes, fourth-order streams and small third order streams from assessment as potential water sources was based on the assumption that large-scale use of these water resources would entail a much more prolonged and entailed evaluation and project development process. Similarly, estimates of potential water use from larger third-order streams assume maintenance of reasonable minimum flows. The exclusion of soils requiring large-scale surface or tile drainage from consideration was based on concerns over potential water quality degradation of surface waters caused by large return flows from ditches and tile-drains. While some surface and tile drainage would still be required from minor soil inclusions within predominantly irrigable soil units, large-scale drainage projects would not be required for development of most of the land considered in this report. Water quality criteria selected for this report are also conservative. Standards of the U.S. Salinity Laboratory (1954), and irrigation soil suitability indices for North Dakota (USDA-SCS 1977) allow for irrigation using water with ECE and SAR as much as 25% larger than the criteria used for this report.

Planning for Irrigation Development

The county reports presented in this study have provided a broad evaluation of the potential for irrigation development in central North Dakota. However, in evaluating irrigation development, additional practical factors should be considered.

Of the approximate 300,000 acres estimated to be readily available for irrigation development, almost 117,000 acres are already permitted. Additional irrigation development will most likely occur as a gradual process. Water use expansion for irrigation in North Dakota has proceeded as a carefully considered and monitored process. Water permits are currently issued at a rate of about 5,000 acres to 10,000 acres per year. It would thus appear likely that annual expansion of irrigation would occur at

a rate not greatly exceeding 10,000 acres per year. An exception would be the development of irrigation districts using water from the Missouri River, which would cause the number of permitted irrigated acres to increase.

The advantages of gradual expansion are that it allows for timely monitoring of the water resource to assure that over appropriation of water does not occur, and it allows time for the expansion of water quality monitoring programs to assure that water quality degradation will not occur.

SUMMARY

There are probably sufficient water and soil resources in eighteen counties of central North Dakota evaluated in this report to allow for irrigation development of about 311,500 acres. This is about three times the total amount allocated in current water permits (116,500 acres). About half of this development would use ground-water sources, and the other half would use surface-water sources. Under optimal conditions irrigation development would be unlikely to exceed a half million acres for the 18 central North Dakota counties studied for this report.

REFERENCES

Omodt, Hollis W. 1982. Written Communication to Larry Knudtson.

USDA-SCS. 1977. North Dakota Irrigation Guide. Lincoln, Nebraska.

U.S. Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. U.S. Dept. Agr. Handbook 60, 160 pp.

EXECUTIVE SUMMARY UPDATE
11/10/98

In 1995 an estimate of potential irrigation acreage available for development in eighteen central North Dakota Counties was presented (Olson and Schuh, 1995). Acreage estimates were based on limitations imposed by irrigable soil overlying aquifers, or neighboring surface-water sources, and on the amount of suitable water likely to be available for irrigation from the supply source. A table (Table ES-1, Page ES-3) summarized the potential irrigable acreage, acres currently under water permit, and potential development over current permitted acreage on a county basis. Since 1995 substantial irrigation development has occurred in some areas. The purpose of this memorandum is to summarize the changes in irrigation development, and update the summary of current and estimated available irrigated acreage, in a revised version of Table ES-1. The revised table is included with this memo. As in the previous report, all county acreage estimates have been rounded to the nearest 500 acres, to be consistent with the general nature of the survey.

Column (10) of revised Table ES-1 summarizes the net change in acreage authorized for irrigation in each county since the end of 1994. The net change is calculated as the difference between newly permitted acreage and the acreage of water permits canceled. The total composite net change for all eighteen counties combined was about 20,000 acres. This total was comprised of 26,000 acres in new water permits since the end of 1994, and about 6,000 acres of older water permits that were canceled because of non application to beneficial use. The largest net gain in irrigated acreage occurred in Kidder County. The net increase of authorized irrigation acreage in Kidder County was more than half of the overall net increase. The second largest net increase occurred in Stutsman County. The remaining counties with a net increase in authorized irrigation acreage were Emmons, Eddy, Grant, Griggs, Morton, Oliver, and Wells counties. No additional water permits have been granted, and irrigation water permits remain essentially the same as in 1995, in Barnes, Foster, Logan, McIntosh, Pierce, and Sheridan counties. Overall net acreage authorized for irrigation has decreased by about 6,000 acres in Burleigh, McLean, and Mercer counties. Estimated potential acreage available for irrigation development was 195,000 acres in 1995, and is now 175,000 acres.

Column (9) of the revised Table ES-1 shows that the developed acreage in Griggs and Stutsman counties is reaching the average estimated in 1995. In column (9) Kidder County has also been developed to near the predicted maximum level in the 1995 report, but that prediction was based on irrigable land limitations rather than water limitations. Water-based limitations of up to twice the original estimate were cited, but development will likely fall short of this because of local well interference and land limitations. One might expect further irrigation development in Kidder County, but at a decreasing rate.

There is large potential for irrigation development in Burleigh and Emmons counties, but it is based on use of a Missouri River water source, and would entail development of infrastructure for conveyance. Possible substantial irrigation development in Grant and Morton Counties is based on surface-water sources, including the Missouri River and waters from the Heart Butte Dam, through the U.S. Bureau of Reclamation. Current irrigation development from the Heart Butte Dam project is about 7,000 acres. This has not changed since 1995. This amount could be nearly doubled.

Net acreage authorized for irrigation has decreased in McLean County. However, irrigation potential in McLean County is large, including substantial potential development from both ground-water and surface-water sources. Some additional irrigation development also appears to be feasible in Barnes, Logan, McIntosh, Mercer, Pierce, Sheridan, and Wells counties.

Details of locations and sources for potential development in each county have not changed substantially, and should be referenced in the original report.

Citations

Olson, J.M., and W.M. Schuh. 1995. Inventory of potential irrigation development in central North Dakota. North Dakota State Water Commission Report. Bismarck.

Table ES-1 REVISED. Summary of land and water resources available for irrigation in central North Dakota, revised November, 1998.

(1) County	(2) Irrigable Land Overlying Aquifers (acres)	(3) Adjusted Irrigable Land Overlying Aquifers (acres)	(4) Amount of Irrigation Development Based On Water Supply Limitations (acres))	(5) Approximate Potential Irrigation Development Based on Most Limiting Factor (acres)	(6) Approximate Potential Irrigation Development Using Surface Water (acres)	(7) Total Potential Irrigation Development (acres)	(8) Approximate Current Water Permits (5/20/95)) (acres))	(9) Approximate Additional Potential Irrigation Development (acres)	(10) Approximate Additional Water Permits Since 12/16/94 (acres)	(11) Comment (acres)
Barnes	24,000	12,000	14,500	8,500	500	9,000	2,500	6,500	0	
Burleigh	34,000	17,000	6,000	6,000	60,000	65,000*	14,500	50,500	-2,500	
Emmons	13,000	6,500	7,000	6,000	39,000	44,500*	13,500	31,000	2,500	
Eddy	20,500	10,000	11,000	4,000	0	4,000	3,000	1,000	500	
Foster	33,000	16,500	12,000	10,500	0	10,500	6,500	4,000	0	
Grant / Morton	9,000	4,500	3,500	2,000	23,000	31,000*	16,000 *(2,000 Grant, 7,000 Morton, plus 7,000 USBR)*	15,000	1,500	May be some difficulty in locating ground-water of good quality
Griggs	32,000	16,000	8,500	8,000	0	8,000	8,500	0†	1,000	May be as much as double projected amount
Kidder	52,000	26,000	51,000	26,000	0	26,000	25,000	1,000	13,500	May be as much as double projected amount
Logan	13,000	6,500	13,500	6,500	0	6,500	2,500.0	4,000	0	May be as much as double projected amount
McIntosh	36,000	18,000	12,000	7,000	0	7,000	500.00	6,500	0	May be as much as double projected amount
McLean	65,000	32,500	17,500	17,500	35,500	51,000	12,000	39,000	-2,500	As many as 14,000 additional acres may be irrigable
Mercer	32,000	16,000	9,500	8,000	7,000	14,000*	8,000	6,000	-1,000	
Morton	26,000	13,500	10,500	9,000	Combined with Grant Cty	Combined with Grant Cty				
Oliver	12,500	6,000	3,500	3,500	6,500	8,500*	8,000	500	1,000	
Pierce	14,500	7,000	5,000	4,500	0	4,500	1,500	3,000	0	
Sheridan	18,000	9,000	10,000	7,500	1,500	9,000	500	8,500	0	Some additional irrigation may be possible
Stutsman	63,000	31,500	18,500	7,000	7,000	7,000	12,000	0†	4,500	Some possible additional irrigation, from limited mining of Spiritwood aquifer
Wells	24,000	12,000	6,500	6,000	0	6,000	2,500	3 , 500	2,000	
Total	521,500	260,500	220,000	147,500	180,000	311,500*	@137,000	@175,000	@20,000	

* adjusted for overlap of ground water and surface-water irrigation lands.

† column 9 does not equal the difference of columns 7 and 8 because water permit acreage estimates exceed estimates of potential irrigation acreage for Stutsman County.

INTRODUCTION

The purpose of this report is to evaluate the potential soil and water resources for irrigation development in selected counties of North Dakota. The first set of counties evaluated will include Barnes, Burleigh, Eddy, Emmons, Foster, Grant, Griggs, Kidder, Logan, McIntosh, McLean, Mercer, Morton, Oliver, Pierce, Sheridan, Stutsman, and Wells Counties. Other Counties may be included at a later time.

The scale of analysis in this report is that of an initial scanning of resources for general planning purposes. It is intended to provide the reader with a broad sense water and soil are availability for irrigation development in selected areas of North Dakota based on current information. It is also hoped that this report will help identify some of the areas with high development potential for closer and more detailed examination. Finally, it is hoped that this report will provide some insight into the limitations and potential difficulties in resource assessment that could affect the course of irrigation development.

The objectives and methods used in this analysis are focused entirely on assessment of soil and water availability for irrigation. Beyond the most general parameters, agronomic requirements are not considered. While soils classified as irrigable are also arable by implication, soil and crop management problems and strategies not involved directly with water application and use are not considered. For example, while the slope of the land is considered from the standpoint of center pivot operation, other factors like fertility, tilth, erodability, and stoneyness that affect farm operation are not. Similarly, while broad limitations in water quality suitable for irrigation are set based on the susceptabilities of certain high value crops, no individual crop is evaluated. Neither are the methods or timing of water applications included.

There are other limitations of which the reader shoud be aware before using this report. One is the limitation of information. North Dakota is fortunate to have an excellent resource for ground water evaluation in its full set of County Ground-Water Study Reports. This information resource is complemented by additional city studies, project studies, and supplemental water resource investigations conducted by the North Dakota State Water Commission and other state and federal agencies. Nonetheless, vital information is limited, and in some cases unavailable. In some counties it is possible that substantial water sources may yet be found through further investigations.

Another limitation is that certain difficulties in water development, such as the potential well yield, cannot be dealt with in a broad scanning report. The variability of aquifer composition and thickness, and localized differences in well yields can increase the difficulty of development in certain areas. Wherever possible these factors are discussed in the report as mitigating considerations for the potential acreage numbers presented. Other limitations, resulting from the analytical assumptions and procedures used in this report, will also be discussed in the presentation of methods.

This report is intended to be a first approximation, an attempt to help put planners in the "ball park". However, actual project siting and development should not be attempted without a much more detailed investigation of local resources and conditions in the areas and locations of the proposed projects.

METHODS USED TO EVALUATE POTENTIAL IRRIGABLE LAND IN CENTRAL NORTH DAKOTA

In assessing the initial feasibility of irrigation three principal limits must be evaluated. First, the amount of land suitable for irrigation, and its location in relation to appropriate water supplies must be evaluated. Second, water supplies capable of supporting long-term sustained irrigation, and the proximity of those supplies to irrigable land must be assessed. Third, the quality of available water, its agronomic suitability, and short-term and long-term effects of irrigation on soil resources must be evaluated. Feasibility evaluations used in this report will be based upon these three criteria. Additional criteria, such as land slopes, large changes in elevation which could cause excessive lift and pumping costs, and large-scale drainage requirements are also considered on a situational basis.

SOIL AVAILABILITY CRITERIA AND METHODS

Factors affecting the long-term irrigability have been extensively studied. Among the most important properties are adequate internal and surface drainage, sufficient permeability to allow for adequate infiltration and adequate internal redistribution of water, and capability to flush salt from the soil profile. Assessment of irrigable land is based on the following criteria.

1. Soil-Association Maps. The desired level of resolution in selection of potentially irrigable land for this study is one section (1 square mile). Detailed soil survey maps are drawn at much higher resolution, and would result in the need for integration of the mapping units for assessment on the section scale. The next largest scale soil map is the soil association map, for which the smallest mapped geographical division is the township. The drawback of the association map is that it is not necessarily accurate on the scale of the individual section. The association map was chosen, because integration of soil types into predominant associations was already performed by qualified soil mappers, using consistent methodologies from county to county. Moreover, relative quantities of individual soil series within the mapped association units are estimated (as percents) , so that a broad quantitative estimate of individual series within the association is possible.

2. Soil Irrigability. Most North Dakota soils have been classified according to potential irrigability and limitations in the North Dakota State Irrigation Guide (USDA-SCS 1977). Three main classes of soils are irrigable, nonirrigable, and conditionally irrigable. Conditionally irrigable soils are considered irrigable with special management. Management requirements may include drainage of water from high water tables, surface drainage, water use limitations such as lower salt or sodium

requirements, and lower application rates to offset problems with inflitration and internal drainage, among other factors.

For this study, soil suitability classifications from the North Dakota Irrigation guide (USDA-SCS. 1977) were composited to form three principle Groups. Group 1 in this study consists of soils that are irrigable without substantial limitations. Group 2 consists of conditionally irrigable soils not requiring large-scale internal or surface drainage. The reason for separation of the conditional class based on drainage is that irrigation development of these soils requires more infrastructure in the form of drainage districts, canals, etc. and greater long-term planning. Developments requiring large-scale drainage are also subject to intense regulatory and political scrutiny, which imparts additional complexity to the planning process.

An additional limit is that of slope. For this study, all soils having slopes of greater than 3% are excluded, and placed in Group 3. While it is recognized that center pivot irrigation can sometimes be operated on a steeper slope, it is our preference that a conservative criteria be placed on soil selection for this report. Thus, in this report, Group 3 soils are nonirrigable, or conditionally irrigable soils with slopes greater than 3% or substantial requirements for subsoil or surface drainage of water.

Computation of Total Irrigable Soil Acreage

For general assessment of county soil resources, the table of soil series acreage from the county Soil Survey is classified into groups based on the North Dakota State Irrigation Guide, as modified above. Estimates of total irrigable soil (Group 1 and Group 2 soil as described above) are derived from summing the acreage of the groups classified. In addition, the county plat book is used to estimate the total amount of land owned by the federal, state, and county government. Amount of municipal land is estimated as one township. For small towns an 80-acre estimate is used to estimate town land. Total government land is adjusted by the proportion of estimated irrigable land (as a percent of total land in the county), and subtracted from the estimate of irrigable land to derive an adjusted estimate of total irrigable land.

DETERMINATION OF POTENTIAL ACREAGE FOR IRRIGATION DEVELOPMENT USING GROUND WATER

There are two primary limiting factors that determine the amount of land that can be potentially developed for irrigation using ground water. These are 1: availability of suitable soil within close enough proximity to the aquifer to allow for cost effective use of ground water; and 2: the amount of water available for irrigation use in each aquifer. These two limiting factors are estimated for each

aquifer. The most limiting acreage for the two criteria is selected for each aquifer, and these are summed to estimate the total county potential for irrigation development.

Soil Available for Irrigation Development

For simplicity, the proximity to water criteria is satisfied by only selecting land classified as irrigable (Groups 1 and 2) directly overlying areas mapped to aquifers. While it might be argued that conveyance of water would be feasible in some circumstances, it can be equally argued that the aquifer boundaries on the county study maps, or other studies used in this report, are somewhat interpretive and by no means absolutely certain as mapped. Also, there will be some areas within mapped aquifers in which saturated thickness, or pumpability will be inadequate for irrigation development. Thus, assumptions allowing for a distance of conveyance from the mapped aquifer would offer no real advantage of accuracy.

Irrigable soil overlying each aquifer was estimated using Soil Survey soil-association maps. The soil-association maps were digitized. Aquifer maps from the county studies, or other water resource publications were also digitized. Scaled aquifer maps were overlain on the soil association maps. Integrated scaled map areas were used to measure total area of the mapped aquifer, and total area mapped to associations containing predominant soils that are irrigable (Group 1 or Group 2 as defined above). Calculated acreage for land classed in predominantly irrigable soil associations overlying aquifers was then further adjusted for irrigability of series within the soil association as defined. Soil Survey definitions of soil association contain estimates of percentages of individual series within the soil association. Series within the association definition were classified according to irrigability, and the total association acreage was multiplied by the percent of irrigable (Group 1 or Group 2 soils) attributed to the association.

Soil-association maps do not account fully for slope of the individual series. For this reason, the percent of land classified in irrigable series, but having a slope of less than 3% was computed using tabulated series acreage in the County Soil Survey . This percent was used to further adjust the amount of total irrigable land according to the criteria of this report. Finally, a contingency factor of 1/2 was applied to all irrigable acreage estimates. This factor was used to account for error and landowner preference. It was also considered desirable that a conservative bias be placed on estimates made in this report.

In summary, potential irrigable land (PIL) was computed for each aquifer as

PIL = acres mapped to irrigable soil association overlying aquifer x
% irrigable series within association x
% of land with slope < 3% in series x
contingency factor (0.5)

For some counties with a significant amount of land covered by lakes and potholes (ex. Kidder and McLean Counties), the procedure was modified somewhat to account for the likelihood of finding suitable land in parcels of size adequate for irrigation.

Water Available for Irrigation Development

Even if there is adequate soil, the amount of water suitable and available for irrigation can be limiting. Water limitations are both quantitative and qualitative.

A. Available Water Quantity . The criterion used for evaluation of water available for irrigation is estimated sustainable yield. While current permits and current use are considered, they are presented only for comparative purposes. The criterion of sustainable yield is selected because it is conservative. It is the estimate of the amount of water that the aquifer should supply for irrigation over an indefinite period. However, it is recognized that in some instances, mining of water (removal at a rate in excess of recharge), would be acceptable for a limited period of time. The primary criterion for limiting water use is adverse impact on other users. For large aquifers with very large initial storage, considerable amounts of water could be mined before adverse impact would occur. Mining would allow use of water in excess of estimates made in this report. For many small aquifers, however, the effects of mining would be almost immediate, and adverse impact would occur quickly. Mining of water would be considered on a case by case basis, and should not be counted as a reliable source of water for purposes of future planning.

The basis for estimating sustainable yield is recharge. Estimating recharge is not a simple matter. There is a large range of variability in aquifers. Most of the aquifers used for irrigation in North Dakota are of glacial origin. Some are confined, and some are unconfined. Some confined aquifers are buried beneath shallow layers of till that are highly weathered and fractured and allow for substantial recharge, while others are deeply buried beneath deep layers of till that are unweathered and highly impermeable. Some are buried river or stream valleys of non glacial origin, and are covered with mixtures of silty and sandy materials that are more permeable than some of the tills. Some aquifers vary from unconfined, to shallow confined and deeply confined in different areas of their extent.

1. For unconfined surficial aquifers recharge is determined by, and is highly sensitive to, climate. The primary factor affecting recharge is precipitation. In North Dakota recharge to unconfined aquifers is correlated primarily with spring snowmelt and precipitation, and in recent years to an increasing effect from fall precipitation. While there is considerable uncertainty and variability, common rule of thumb estimates used for a "first estimate" by water managers is three to four inches

per year in the eastern part of North Dakota. For this report, the estimate of sustained yield for unconfined aquifers is based on three to four inches per year of recharge. In some cases, it may be decreased slightly to account for local climatic differences.

2. For confined aquifers, recharge rate is determined primarily by leakance from the overlying aquitard into the aquifer. This is controlled by the hydraulic conductivity of the aquitard materials and the vertical hydraulic gradient driving water through it. Confined aquifers in North Dakota are sometimes initially artesian, and have water pressures above the aquifer, or even above land surface. In such cases, mining of water is often feasible for the initial development period. As the aquifer is pumped and water pressure in the aquifer drops below the water level of the overlying aquitard, a hydraulic gradient develops, causing recharge from the aquitard to the aquifer. According to a survey study by Shaver (1994) common hydraulic gradients from glacial till to aquifer are between 0.1 and 0.3. Hydraulic gradients of 0.2 to 0.3 from the till to the aquifer were common for the Carrington aquifer in one study (Schuh et al. 1994). The larger the hydraulic gradient, the larger the amount of water recharging the aquifer. Large-scale development would result in a decline of water pressure, or water level. The maximum expected gradient would occur when water in the aquifer is pumped below the level of the aquitard, causing near atmospheric pressure at the upper boundary of the aquifer. In such a case, the vertical hydraulic gradient through the aquitard would be about one.

For this study, the following information is used to provide a rough estimate of recharge for confined aquifers.

(a) A study by Rehm et al. (1982) indicated that recharge through the till ranged from 0.4 to 1.6 inches per year.

(b) 10^{-8} m/s (0.003 ft./d) is a commonly measured hydraulic conductivity for saturated glacial till (within a very wide range of values). It is slightly below the median conductivity for weathered till in a review of the literature by Shaver (1994), and close to the median conductivity for the range of hydraulic conductivities of unweathered tills. Using a gradient of 0.1 to 0.3 , recharge rates of 1.2 to 3.7 inches per year would be expected.

(c) A model of recharge to the Sundre aquifer by Pusc (1987) seemed to function best with a fitted recharge parameter of about 0.5 inches per year. The Sundre aquifer in the area modeled is overlain by highly impermeable unweathered glacial till.

(d) Computations of "leakance" from saturated unweathered glacial till having a conductivity of 5×10^{-10} meters per second using a simple analytical model were provided by Shaver (written communication, January 1995). Shaver's calculations indicated that after about 40 ft. of drawdown in the till, leakance would be about 0.8 inches per year. According to Shaver, for deeply buried portions of the Spiritwood aquifer, that are overlain by unweathered till, the lower range of leakance values (0.3 to 0.4 inches per year) are likely more common (verbal communication, March 1995).

For confined aquifers, two recharge values are used, based on depth. It is assumed that a glacial till aquitard of more than fifty feet overlying an aquifer is at least partly unweathered, and has a lower hydraulic conductivity. If the till aquitard has a depth of less than fifty feet, it is assumed to be weathered, and possibly fractured in places. A higher hydraulic conductivity and recharge value is assumed. For unweathered till, a base recharge value of about 0.3 to 0.4 inches per year is assumed, based on items (c) and (d) above. For weathered till, a base recharge value of 1.2 inches per year is assumed, based on items (a) and (b) above. The 1.2 inch per year value is the bottom of the range in item (b), and the approximate midpoint of the range for item (a).

Not all aquifers are simply confined or unconfined, or deeply or shallowly confined. Many, in fact most, vary in status and depth of confinement. For this reason, discretionary adjustments of recharge estimates within the established ranges are made in some cases, based on aquifer depths as indicated on drill logs, and on information provided in County Study reports and other sources. For aquifers that are variably confined and unconfined recharge values of 2 or 2.5 inches are frequently used, depending on location and circumstances. For aquifers varying from deep to shallow confinement, upward adjustments from the deep confined value (0.3 inches per year) are made. Values of 0.5 or 0.6 inches per year are most commonly used.

B. Water Quality. In addition to quantity, the quality of available water must also be considered. Water quality factors affecting irrigation usability have been discussed by the U.S. Salinity laboratory Handbook Number 60 (1954), and have been adapted for North Dakota in the North Dakota Irrigation Guide (1977). Main factors considered in irrigation suitability are sodium content, as indicated by the sodium adsorption ration (SAR), salinity, as indicated by electrical conductivity (ECE), and boron content. These three factors are considered in evaluation of the suitability of North Dakota water supplies for irrigation.

1. Sodium adsorption ration (SAR) is important as an indicator of the compatibility of a water supply with a specific soil type. Excessive sodium causes puddling or slaking of the soil, and results in poor infiltration and a hard crusted soil surface. In the extreme, sodium buildup can also be

toxic to the crop. Physical effects caused by large SAR are offset by higher overall salt content in the water. In this study, a maximum SAR of 6 is allowed as an upper boundary, although with proper management, higher SAR values may acceptable on some soils. The SAR of 6 is considered to be a conservative indicator.

2. Soil salinity, as indicated by electrical conductivity (ECE) at higher levels can offset the physical effect of high SAR. However, high salt content inhibits crop growth, and can prevent effective water and nutrient uptake. If the soil is appropriately flushed each year, the soil profile should eventually reach an equilibrium with the SAR and ECE of irrigation water. Crops vary in their susceptibility to salt. The North Dakota Irrigation Guide suggests a maximum ECE of 1,800 to 2,250 µs/cm for irrigation. However, some crops, like potatoes, are moderately susceptible or susceptible to salinity, and significant yield reductions can occur at ECE above approximately 1700 µs/cm (Hoffman 1981). For this reason, an upper limit of approximately 1500 µs/cm is set on irrigation water for this feasibility assessment.

3. Boron concentration is another potential problem in irrigation. Crops vary in susceptibility to boron. Some crops, such as alfalfa, are very tolerant and may benefit from high boron. Most others can undergo toxic effects. Potatoes, for example, are moderately susceptible to boron, and should not be irrigated with water having more than 2 mg/L boron. For this feasibility study, the 2 mg/L limit will be placed on irrigation water.

ECE, SAR, total dissolved solids (TDS), and boron are all cross correlated. Using water chemistry data from all wells in Burleigh county aquifers, it can be seen that ECE correlates well with TDS. The 1,500 µs/cm ECE limit corresponds to an approximate 1,000 mg/L TDS (Figure 1). 1,500 µs/cm ECE also corresponds to a mean SAR value of approximately 6 (Figure 2), and thus corresponds well with the SAR limiting value established. Boron values also correlate highly with SAR. In all Burleigh county water samples, there were no boron values above 2 mg/L in waters having SAR of 6 or less (Figure 3).

Accounting for Variations in Water Quality

There is a large variation in water quality components between and within aquifers and surface water sources. Both collectively (all wells in a given county or area) and within individual aquifers, water quality indicators (Boron, ECE, SAR) are log normally distributed. Examples of these is shown using a composite all of the Burleigh county well data as shown on Figure 4. Thus, for each aquifer, the chance of finding suitable water in a given well can be defined by the probabilities (x axis)

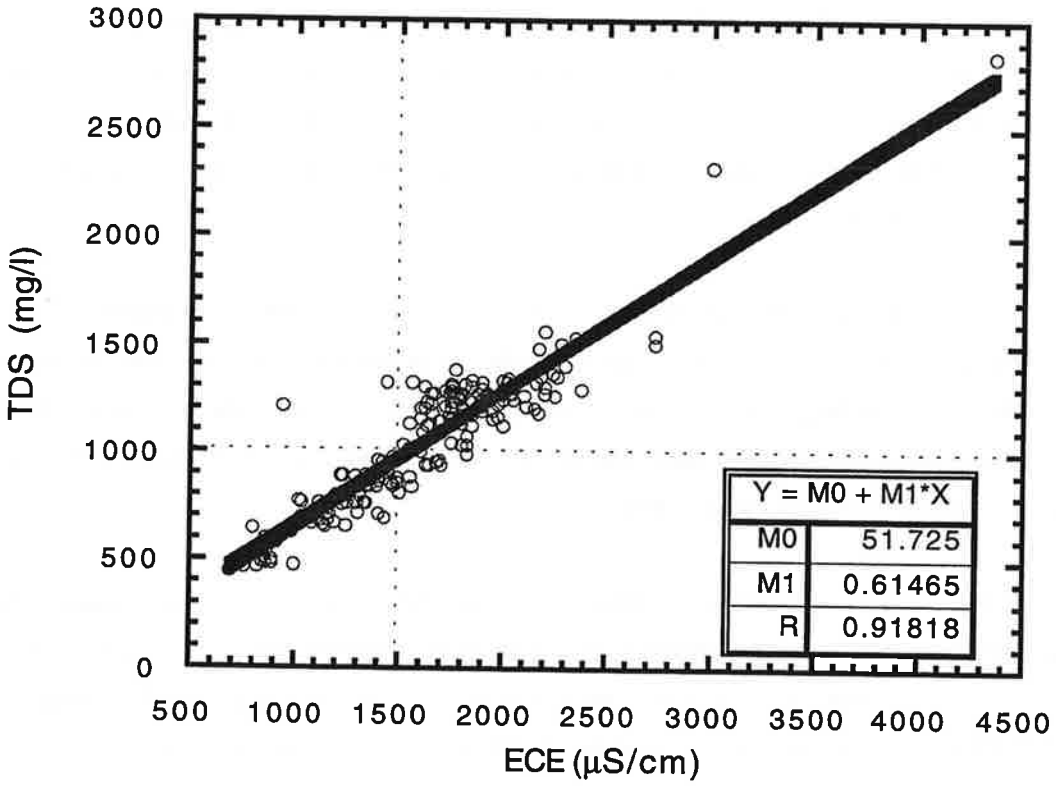

Figure 1. Total dissolved solids (TDS) versus electrical conductivity (ECE) for all water samples tested from aquifers of Burleigh County.

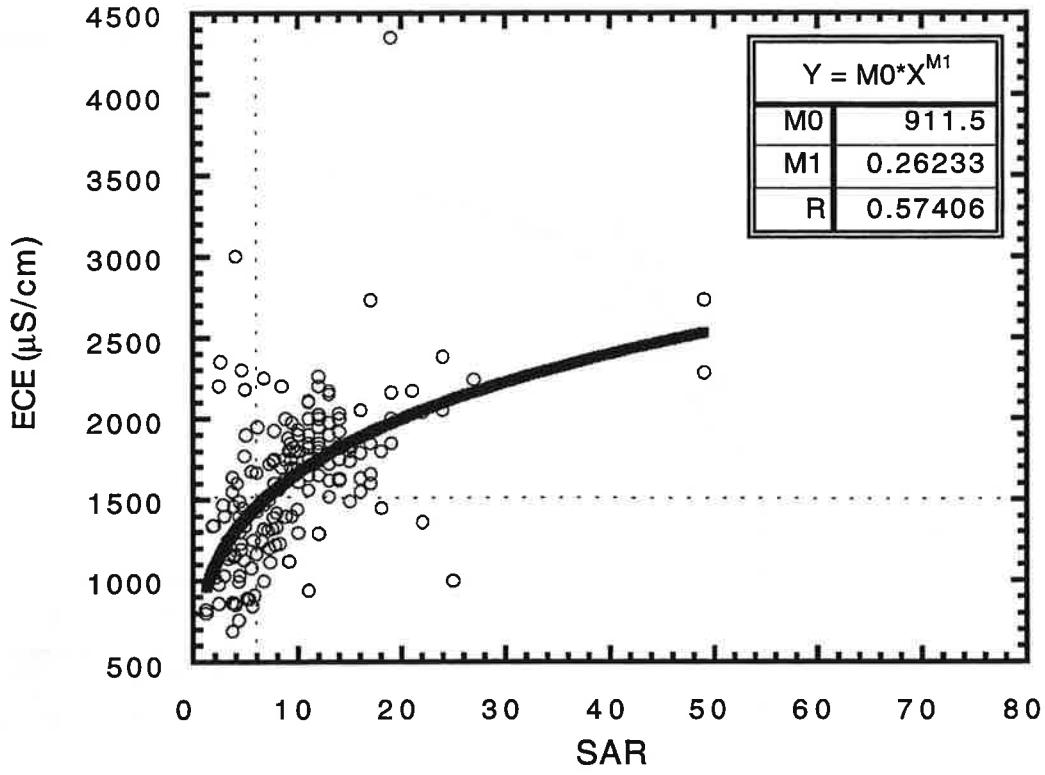

Figure 2. Electrical conductivity (ECE) versus sodium adsorption ratio (SAR) for all water samples tested from aquifers of Burleigh County.

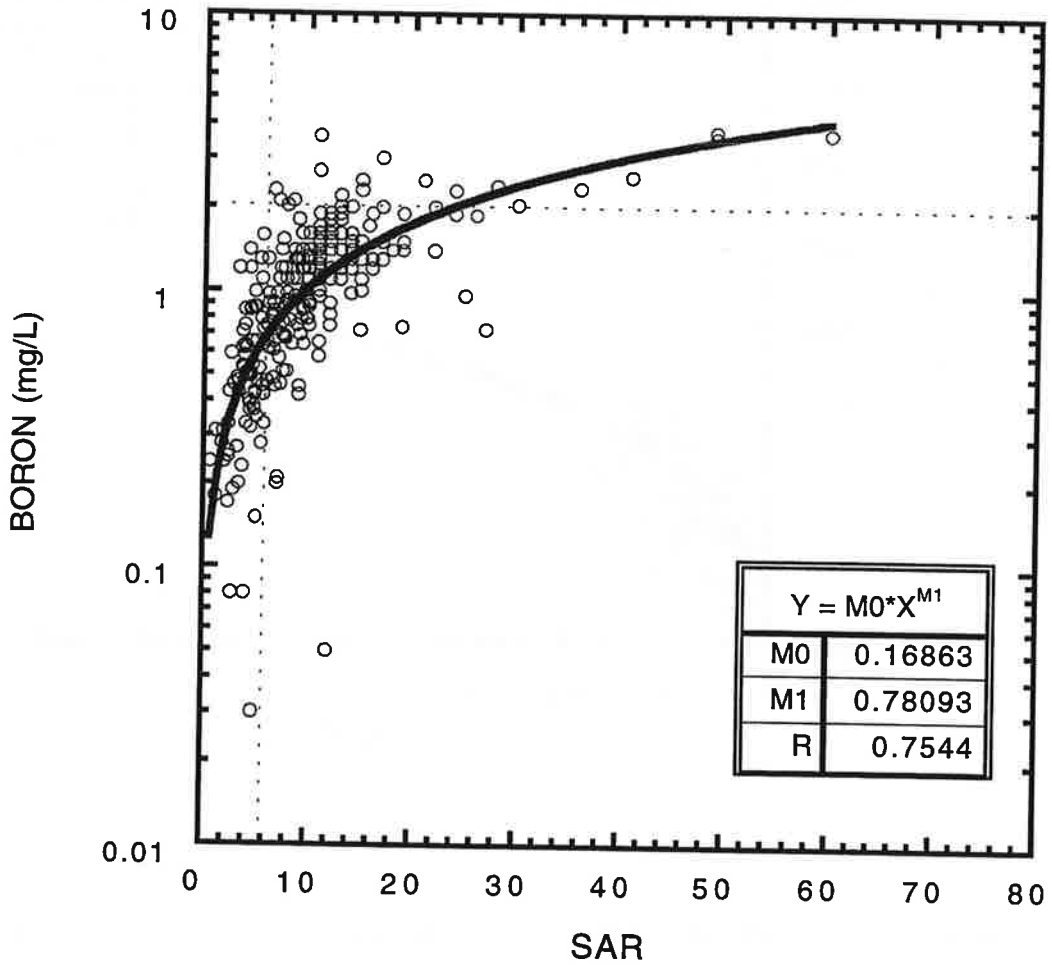

Figure 3. Boron (mg/L) versus sodium adsorption ratio (SAR) for all water samples tested from aquifers of Burleigh County.

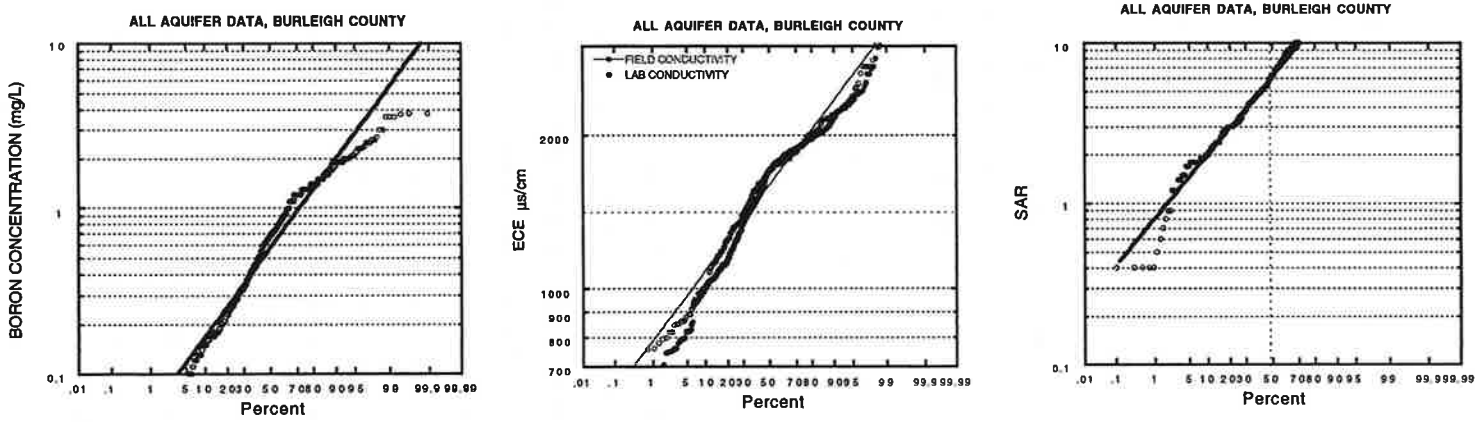

Figure 4. Probability distributions of Boron, ECE, and SAR for all Burleigh County well data.

corresponding to the upper limits (y axis) of the indicators. For example, for a random placement of a well in any aquifer in Burleigh County, the chances of pumping water with an ECE of 1,500 µs/cm or less is about 60%. However, there is a considerable difference in water quality distributions between individual aquifers.

For small aquifers some account must be made for the likely degradation of water quality at any given withdrawal point over time. Sources of poor quality water are usually leakance from bedrock or till, or waters in close proximity to bedrock or till boundaries. However, if an aquifer is stressed by pumping, the chances of drawing water from areas influenced by bedrock or till boundaries to the well increase. This is particularly true of wells placed near the aquifer boundaries, or near the boundaries of aquitards within the aquifers. A decline in water quality was noted by Randich and Hatchett (1966) following a two-day pump test on the McKenzie aquifer.

In order to account for the possibility of lower water quality, probability plots for ECE, SAR, and Boron in each aquifer were plotted, and limiting probabilities for each criterion were tallied. The probability of finding water suitable for irrigation was determined by selecting the most limiting of the three criteria, and using the fractional probability as an adjustment factor for usable water. Thus, sustainable yield is multiplied by the water quality probability factor to obtain a final estimate of water available for irrigation.

Discussion of Water Quality Criteria

The water quality criteria set for this study are conservative. But other factors indicate that they should be conservative. First, irrigation in central North Dakota will not be likely to be implemented with large-scale drainage. Irrigation in the arid southwestern parts of the United States has always been implemented with coordinated drainage to assure return flows of waters used to flush salts from the soil profile. In North Dakota, flushing will likely cause salts to concentrate in the subsoil, where it will remain. Research by Reichman and Trooien (1993) in Burleigh County has indicated that slowly permeable soils can be adequately flushed and maintained. Eventually soil salinity and SAR should be in approximate equilibrium with the irrigation water added. There is no compelling reason to assume that this will result in destruction of the soil, if properly managed. Similar soils in Alberta have been irrigated and internally flushed for almost a century without degradation. Also, internal flushing avoids the water quality degradation of source waters, through the avoidance of high salt-laden return flows. However, without the ability to totally remove salts added to the soil and vadose zone it would seem unwise to heavily overload the soil with salts.

Computation of Water Available for Irrigation Development

The amount of water available for irrigation development is estimated by first calculating sustainable yield, and then adjusting the estimate for water quality limitations. Recharge estimates (R) in inches per year are made for each aquifer as cited above. Values are tabulated for each aquifer. It is assumed that average water use will be about 12 inches year over an extended period. It is also assumed that only the area directly overlying the aquifer will contribute to actual recharge. Sustainable yield (SY) is then computed as recharge (inches per year) divided by 12 inches per year , multiplied by the recharge area [surface area of the aquifer, (A)]. Finally, the estimated sustainable yield is multiplied by the water quality probability factor (Q_W) to estimate water available for irrigation development.

In summary, potential irrigation water (PIW) is computed as

$$PIW = R/12 \times A \times Q_W = SY \times Q_W$$

In some cases, such as Kidder County, adjustments are made to account for additional recharge due to runoff and lack of external drainage, which results in an additional contribution to recharge.

Estimating Potential Irrigation Development Acreage From Ground Water

For each county, potential irrigable land (PIL) and potential irrigation water supply (PIW) are estimated for each aquifer. The most limiting of the two resources is selected as the limiting acreage for the aquifer. If the total of estimated potential development for any aquifer is less than one quarter section (130 acres on a center pivot) irrigation development is considered to be impractical and the amount of potentially irrigable land is counted as 0. The summary of potential irrigation expansion in each county is computed by summing the limiting resource for all of the aquifers.

Additional Discussion

The criteria discussed above have been chosen to provide a systematic and consistent framework for evaluation. While the authors of this report consider the criteria to be conservative, it is hoped that methods have been consistent enough that others with more knowledge or local experience might draw their own conclusions and adjust their investigations and project plans accordingly. It is also hoped that as further exploration occurs, the numbers in this report can be appropriately adjusted.

There are some elements of development that cannot be dealt with quantitatively and which can be troublesome for a report such as this. One limitation is the lack of information. While there is substantial information available, knowledge of the location and extent of ground water resources in North Dakota is far from complete. In some counties, Stutsman among them, further exploration might

prove to be highly productive. We can only evaluate available water based on what has been published at this time.

In addition, translation of available water or land to actual irrigation development potential is made more difficult by certain factors that are difficult to quantify. For example, aquifer boundary conditions, or local limits in pumping rates, can vary considerably. A few large wells in thick and highly transmissive aquifers are much more easy to implement than a large number of manifolded wells in a thinner or less transmissive portion of the aquifer. In some cases, not only the amount of water available, but the location and pattern of development can be critical. If irrigation development occurs in tracts that mutually interfere with the pumping of water, it is possible that overall development will be less than optimal. Also, where the probability of finding water of suitable quality is low, the difficulty of finding the water of suitable quality is not considered in our probability analysis. The water may be there for use, but how much exploration is needed to find it, and does it justify the cost?

Because of these limitations, it is stressed that estimates of potential development acreage do not always tell the whole story. Wherever possible, we have attempted to make the reader aware of some of the mitigating factors through brief additional discussion concerning the values of the final numbers. In some cases, the experienced intuition, or "gut feeling" of the managing hydrologist for the area concerning the limitations of the numbers is added. In summary, estimates in this report are to be considered as a starting point for further investigation.

DETERMINATION OF POTENTIAL ACREAGE FOR IRRIGATION DEVELOPMENT USING SURFACE WATER

Potential surface-water supplies for irrigation development in Central North Dakota are found in the Missouri River and its major impoundments, Lake Sakakawea, Lake Oahe, and Lake Audubon; in major tributaries of the Missouri River, including the Knife, Heart, Cannonball, Cedar rivers; in minor tributaries of the Missouri River, both direct and indirect; in project-related conveyance facilities, such as the McClusky Canal; and in numerous lakes and potholes distributed across the landscape.

For the purpose of this report, small lakes and potholes are excluded from consideration because of the complexities involved with lake hydrology and because of competing recreational and wildlife interests. While some inland lake waters would likely be available for use, they would have to be considered as individual cases. Smaller direct and indirect tributaries of the Missouri River are also excluded because of their intermittent nature. Many of these sources are currently used for spring irrigation of hay land using water spreading methods, and would not be dependable for irrigation through the entire growing season.

The most extensive supply of surface water is the Missouri River. Missouri River water is treated as essentially unlimited in this report. Other factors, including available irrigable soil, distance and expense of transport, and static lift from the river are considered to be more likely limits than the water supply in itself. With the Missouri River, waters from Lake Oahe, Lake Audubon, and Lake Sakakawea are treated as essentially unlimited. Lake Audubon waters have federal restrictions and requirements that must be met by potential users. Other surface waters having federal requirements and limits are those conveyed from Lake Audubon in the McClusky Canal, and authorized releases of water for irrigation from Lake Tschida on the Heart River, by the U.S. Bureau of Reclamation (USBR). Additional surface waters in major tributaries that do not have federal requirements and limits are those of the Knife and Cannonball Rivers, and portions of flow in the Heart River. Potential irrigation from these sources is considered on a case by case basis.

Irrigation From the Missouri River and Reservoirs in the Missouri River System

Estimates of potential irrigation from the Missouri River, Lake Sakakawea, and Lake Oahe are based on proximity of irrigable land, static lift, and distance of the overall project from the source. The static lift criterion is based on the expense incurred in construction of high-pressure pipe lines for conveyance of large quantities of water. Somewhat arbitrarily, 260 feet is the upper limit placed on static lift from the Missouri River to irrigable soil. This is based on calculations of marginal feasibility for development of 2,000 to 3,000 acres of irrigation from the Sheyenne River over a similar lift (Cline et al. 1993). It is realized that the larger the project, the greater the possibility of absorbing the additional cost of the added lift. Land proximity to the river is set at a minimum of five miles distance from the river for first irrigation. This limitation is based on the same Sheyenne River study cited above. Maximum distances of development are set at somewhere between seven and ten miles from the river, depending on the individual development site and the amount of land available. Water quality criteria for the Missouri river are shown for Burleigh County on Figure 5. Boron content is fractional and insignificant. ECE are all below 1000 µs/cm , and SAR are all below 2. Water quality in the Missouri River is not limiting with respect to any of the three criteria (ECE,SAR, Boron) applied in this study.

Additional Discussion

As with ground water, the methods used for assessment of potential irrigation development from surface water are approximate. Development is premised on tracts of irrigable land sufficiently compact to justify the infrastructure needed to supply them. These tracts are located by map surveys of soils, elevations, and slopes. Further detailed analysis of sites is needed to justify further planning for most of these sites.

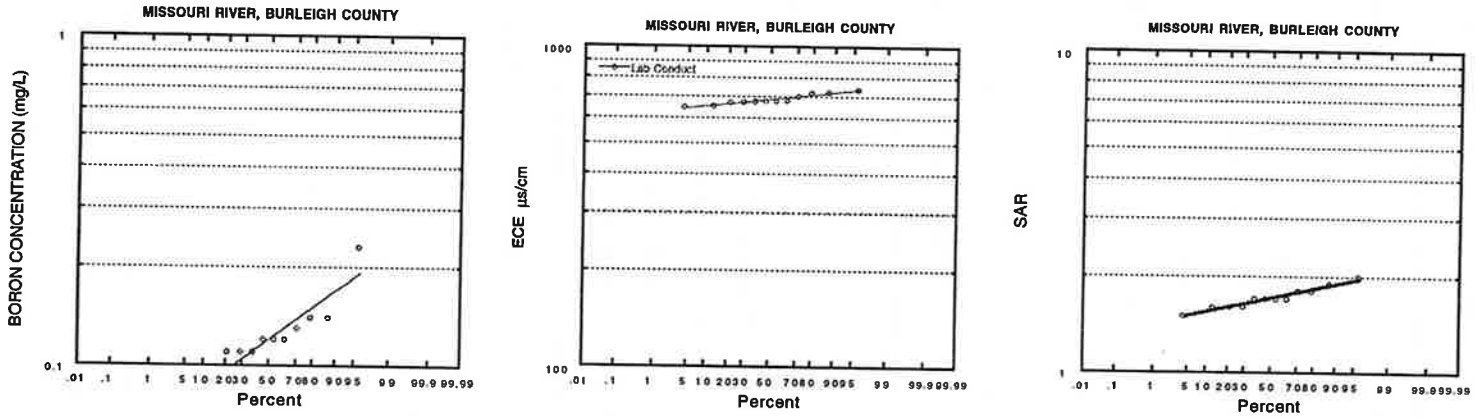

Figure 5. Probability distributions of Boron, ECE, and SAR for water samples taken from the Missouri River in Burleigh County.

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Potential Irrigation Development in Barnes County, North Dakota

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT FOR BARNES COUNTY

The single largest source of irrigation water in Barnes County is the Spiritwood aquifer, which underlies most of the northwestern portion of the county. Smaller but significant aquifers are the Sand Prairie aquifer and the Stoney Slough aquifer. About 24,000 acres overlying aquifers in Barnes County have soils classified as irrigable or conditionally irrigable, have slopes of less than 3 %, are free from substantial surface and subsurface drainage requirements, and lie in parcels of sufficient size for irrigation. In this study, estimates of potentially irrigable land are based on total land classified as irrigable, multiplied by a contingency factor of 1/2 to account for potential error, and land owner preferences regarding development. The contingency factor is also intended to lend a conservative bias to this report. Application of the contingency factor results in an estimate of at least 12,000 acres of irrigable land in Barnes County.

Water quality for irrigation is variable. About 70% of water samples collected from the Spiritwood aquifer are of suitable quality for irrigation, based on the criteria of this study. The unconfined Sand Prairie aquifer has excellent water for irrigation. Sufficient water quality data to individually assess the other four aquifers in Barnes county was not available. Where water quality data was lacking suitability of water quality for irrigation was estimated based on similarity to the Spiritwood and Sand Prairie aquifers. Estimates of long-term sustainable yield indicate that sufficient water for about 14,500 acres of irrigation is possible on a long-term basis.

Potential irrigation development is estimated by summing the most limiting resource (irrigable land or water) for each aquifer. **Results indicate that development of at least 9,000 acres for irrigation should be feasible in Barnes County.** Estimates of potential irrigation development in this report compare with a total of 2,350 acres currently permitted for irrigation in Barnes County. This estimate is likely conservative, and it would not be implausible that as much as half again the 9,000-acre estimate, might be developed in carefully monitored stages.

POTENTIAL IRRIGATION DEVELOPMENT IN BARNES COUNTY NORTH DAKOTA

The purpose of this report (chapter) is to provide an evaluation of land and water available for potential irrigation development in Barnes County. Methods of assessment used in this report were designed to provide a conservative estimate. These methods were described in a previous introductory section. It is emphasized that the findings of this report are based on general information. Estimates of irrigation potential are preliminary, and should not be used for individual project planning without further local in-depth analysis. For the sake of continuity in computation, data on computation tables are provided to the nearest digit. However, this should not lead to the conclusion that this report can estimate acreage with such a high level of precision. **In the text of this report, the final summary estimates resulting from table computations are rounded to the nearest 500 acres.** These final rounded numbers reflect more appropriately the general character of these estimates.

In Barnes County there are currently 20 water permits for the irrigation of 2,351 acres. Actual water use varies. Between 1991 and 1993 largest irrigated acreage was 1,647 in 1991. Least irrigation (593 acres) occurred in 1993, which was an extremely wet year. 1,802 acres are permitted for irrigation using ground water. 548 acres are permitted for irrigation from surface water. All surface water used for irrigation is withdrawn from the Sheyenne River.

IRRIGATION DEVELOPMENT FROM GROUND WATER

Assessment of potential irrigable land in this report will not be limited to or based on actual current water permits, or on current actual irrigated acreage. Rather it will be based on evaluation of the water and soil resource. In Barnes County seven principal aquifers have been identified as potential sources for irrigation. These are listed on Table 1. There are two possible limiting factors affecting potential irrigation development using ground water. These are (1) irrigable land within practical distance of the water source , and (2) available water of suitable quality in close proximity to irrigable land.

Total Irrigable Soils

There are approximately 922,940 acres in Barnes County. According to a study conducted by North Dakota State University (NDSU) there are about 875,087 acres of irrigable and conditionally irrigable land in Barnes County (Omodt, written communication, 1982). About 95 %, is classified as conditionally irrigable because of slope, drainage requirements, or slowness of internal drainage.

Table 1. Resources for potential irrigation development in Barnes County, ND. ECE is the electrical conductivity of water; SAR is the sodium adsorption ratio of water; and Boron is the concentration of boron in water. Potential irrigable acres based on water limitations (column 8) are calculated by multiplying the total acreage (column 7) by the recharge coefficient coefficient in column (6) as described in the text, and by adjusting for water quality (column 5). Land mapped in irrigable soils series, and having a slope of less than 3% (column 10) is calculated from land area mapped in irrigable associations overlying the aquifer (column 9), adjusted for the proportion of the association attributed to soils of irrigation suitable series, and by an adjustment factor (0.49) accounting for slopes greater than 3%. The final estimate of potential irrigation development (column 11), is half of column 10. **Bold type** indicates most limiting estimate of potential irrigation, used in final estimates of potential irrigation development. (c) means aquifer is confined with less than 50 feet of overburdon. (c†) means that aquifer is deeply confined, having more than 50 feet of overburdon. (u) means that aquifer is unconfined. (c/u) means that aquifer is variably confined and unconfined.

(1) WATER SOURCE	(2) ECE %<1500 µS/cm	(3) SAR %< 6	(4) BORON %<2 mg/L	(5) WATER QUALITY COEFFICIENT	(6) RECHARGE COEFFICIENT	(7) AREA OVERLYING AQUIFER acres	(8) POTENTIAL IRRIGABLE ACRES-WATER LIMIT acres	(9) LAND MAPPED IN IRRIGABLE ASSOCIATIONS acres	(10) LAND MAPPED IN IRRIGABLE SOIL SERIES, SLOPE < 3% acres	(11) POTENTIAL IRRIGABLE SOIL OVERLYING AQUIFER acres
Bantel - c/u	-	-	-	1*	0.21	1,888	397	1,280	414	**207**
Sand Prairie -u	100	100	100	1	0.33	5,804	1,915	5,804	1,478	**739**
Spiritwood -c†	90	70	99	0.7	0.05	116,800	**4,088**	47,116	15,237	7,619
Stoney Slough -u	-	-	-	1*	0.33	18,688	6,167	18,528	4,721	**2,361**
Valley City - c/u	-	-	-	1*	0.21	7,936	1,667	7,936	1,671	**836**
Wimbledon -c†	-	-	-	1*	0.05	70	4	70	0	0
Undifferentiated	-	-	-	0.7*	0.21	2,272	334	2,272	579	**290**
Total						153,458	14,572	83,006	24,100	12,052

* No water quality data were available. Used probability of nearby, or similar aquifer.

The classification used in this report is a much more restrictive subset of that used in the NDSU study. A soil association map (USDA-SCS, 1990) is provided on Figure Ba-1. All soils requiring extensive surface or internal drainage are excluded from consideration, and all soils having slopes of more than 3 % are also excluded. Using the criteria of this study, about 35,335 acres are classified as Group 1 (irrigable without limitations, slope less than 3 %) soils based on Barnes County SCS soil survey tabulations. There are an additional 161,030 irrigable acres in the Group 2 category (irrigable with limitations). Thus, based on soil suitability alone, there are about 196,365 acres of potentially irrigable land.

All federal, state, and municipal land is excluded from the potentially irrigable acres. There are about 11,964 acres of state and federal land, and about 13,440 acres of municipal land, for a total of about 25,404 acres of government land. About 21 % of all land in Barnes County is classified as irrigable according to standards of this study. Applying this proportion to government land gives 5,334 acres of excluded land that might be considered irrigable. After subtracting estimated irrigable government land, approximately **191,000** (191,030) **acres would be considered to be potentially irrigable based on soil factors alone.** A map of soil Groups (irrigable, conditionally irrigable, and non irrigable) as defined for this study is provided on Figure Ba-2.

Estimates of Irrigable Soil Overlying Aquifers

The overall estimates of irrigable soils discussed above were taken from soil survey summary tables and were adjusted for slopes greater than 3%. Estimates of irrigation-suitable soil overlying aquifers were calculated by integrating the areas of mapped soil associations within mapped aquifer boundaries. Areas mapped to soil associations considered to be predominantly irrigable were adjusted by the percent land individual soil series classified as irrigable within the association. Barnes County soil summary table data indicated that about 49 % of soils mapped in series considered irrigable, had slopes of less than 3 %. Irrigable series were thus adjusted to account for slopes greater than 3% using a factor of 0.49. Finally, a 1/2 contingency factor was applied to all estimates of irrigable soil area. Results in Table 1, column 11, indicate that **about 12,000 acres** (12,052 acres) **of land overlying aquifers would be considered as potentially irrigable based on soil suitability alone.** Most of the potential development is from the Spiritwood aquifer. The second largest location for potential development overlies the Stoney Slough aquifer. Most of the irrigable soils mapped were in Group 2 (irrigable with limitations).

Irrigable Land Overlying Aquifers Based on Water Supply Limitations

Ground-water resources in Barnes County have variable quality for irrigation use. Between 70 and 100 % of the ground water from aquifers considered on Table 1 are of suitable quality for

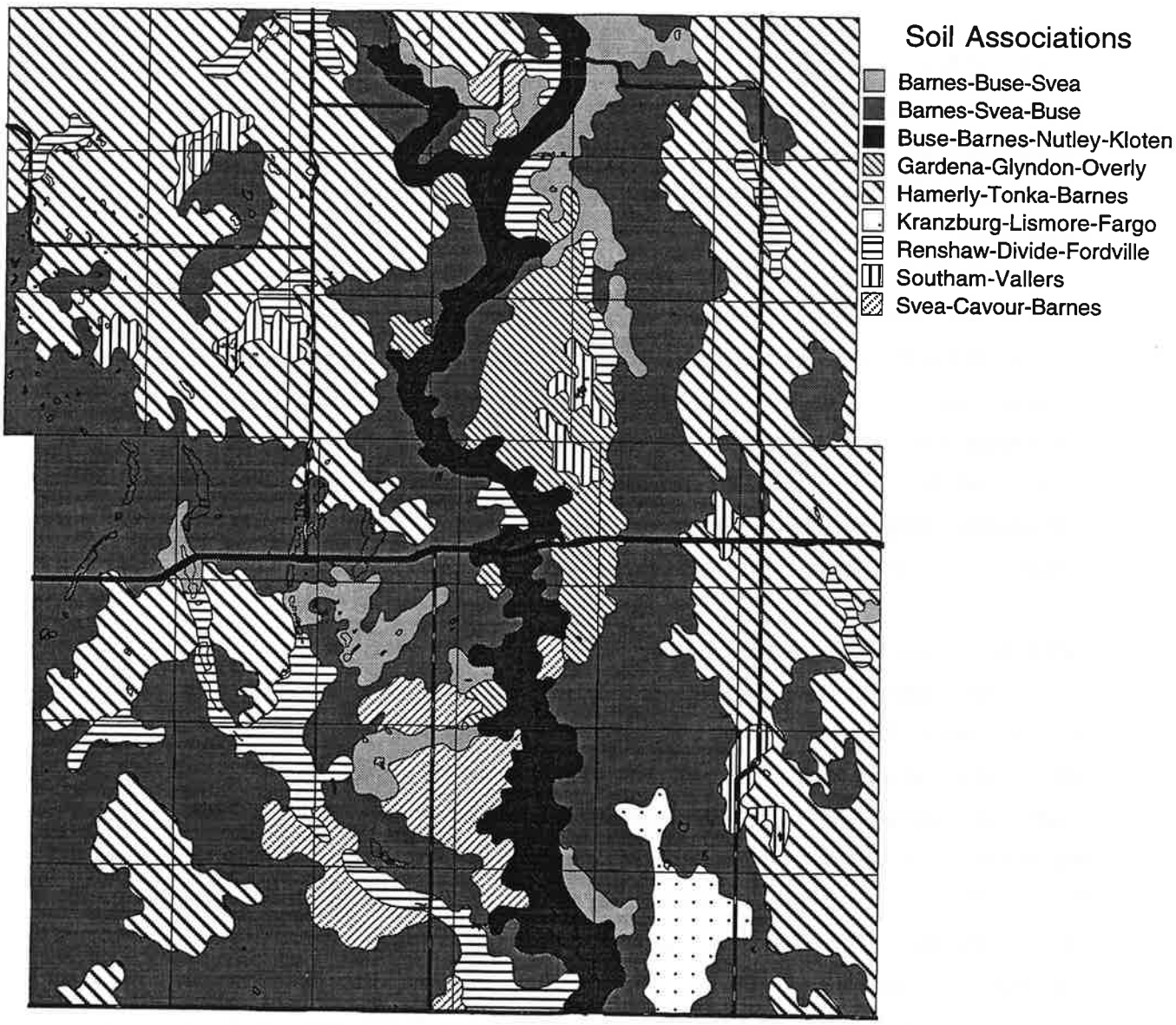

Figure Ba-1. Soil association map of Barnes County ND. (From Barnes County Soil Survey, USDA-SCS , 1990).

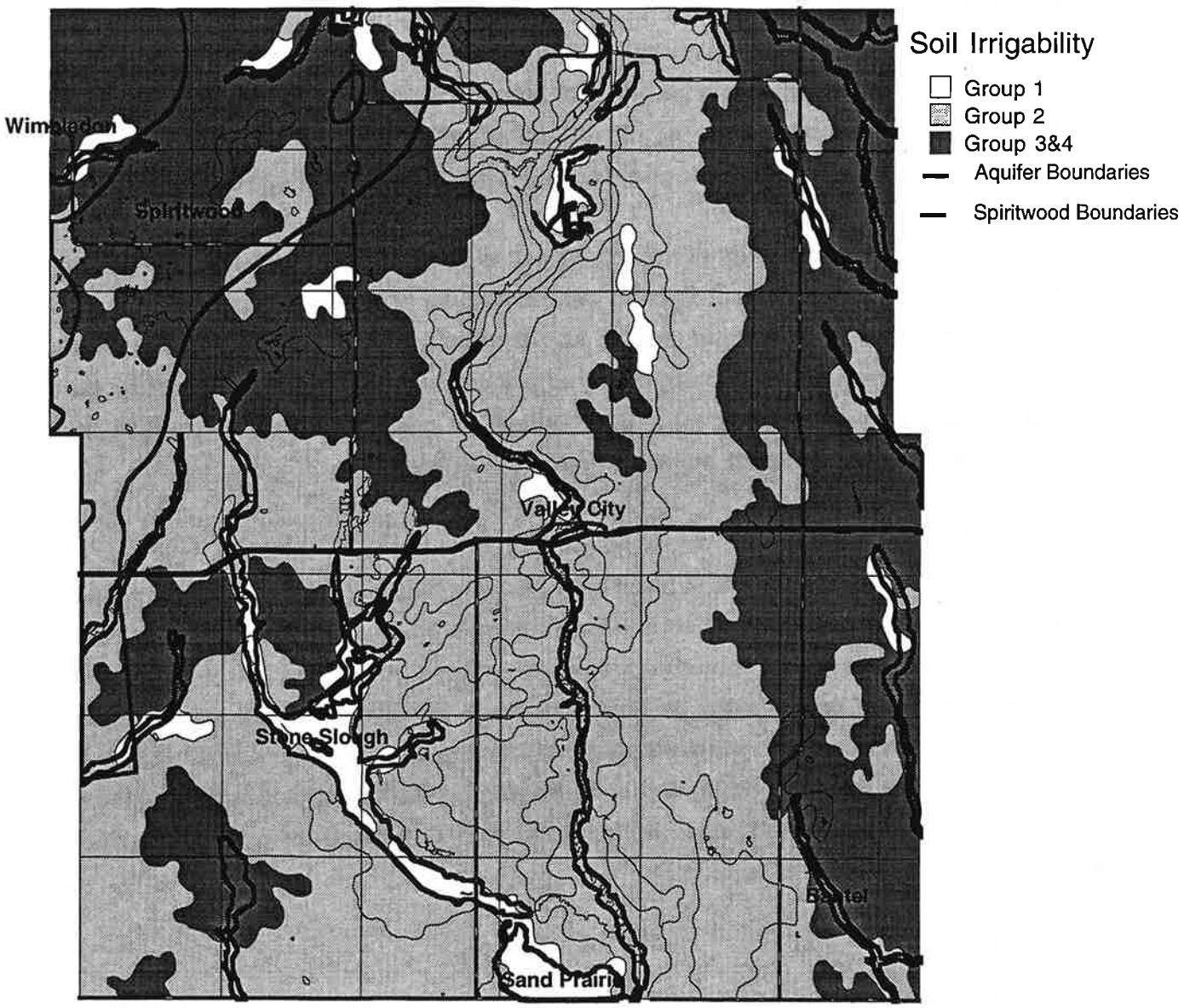

Figure Ba-2. Map of boundaries of the principal aquifers in Barnes County, ND. (From Kelly, 1966).

irrigation. Water quality is evaluated on the basis of suitable electrical conductivity (ECE), sodium adsorption ratio (SAR), and Boron concentration (Table 1). Estimates of water available for potential irrigation are based on an estimated recharge of 0.3 inches per year for deeper confined aquifers in glacial till, 1.2 inch per year for shallow confined aquifers, 2.5 inches per year for aquifers that are partly confined, and partly unconfined, and 4 inches per year for unconfined aquifers. Irrigable acreage for each aquifer is then calculated by assuming an average of 12 inches per acre per year irrigation. The recharge coefficient is the estimated recharge divided by the 12-inch use estimate. Recharge coefficients calculated for 0.3, 1.2, 2.5, and 4 inches are 0.025, 0.1, 0.21, and 0.33, respectively. In some cases, depending on the aquifer, ranges of values between these coefficients are selected.

Irrigation acreage based on sustainable water use is further adjusted by the water quality coefficient, which is the probability of obtaining water suitable for irrigation in a given well (Table 1, column 5). The most limiting parameter (of ECE, SAR, Boron) is used to adjust for water quality. The resulting irrigable acreage estimate based on recharge and water quality is in Table 1, column (8). **About 14,500 acres** (14,572 acres) **are estimated as potentially irrigable, based on estimates of available water of suitable quality for irrigation.**

Potential Irrigation Development from Ground Water in Barnes County

The most limiting factor in Table 1 [water limiting (column 8); or soil limiting (column 11)] is used to estimate potential irrigation development from ground water in Barnes County. Parcels of land less than 130 acres are not included in the sum of potentially irrigable acres. **The sum of potentially irrigable acres based on the most limiting resource is about 8,500 acres** (8,521 acres). This compares with about 1,802 acres already permitted for irrigation using ground water in Barnes County, for an increase of about 6,500 acres of development. If the 1/2 contingency factor had not been applied to availability estimates, the estimated total of acreage for potential irrigation development would be about 12,500 acres.

Additional Comments

The Spiritwood aquifer is extensive in Barnes County. It is not implausible that in some areas recharge to the Spiritwood aquifer might exceed the estimates used in this report. However, lacking further information, this cannot be stated with certainty. Moreover, for a large aquifer, like the Spiritwood, a substantial amount of development might be allowable on the basis of limited mining, and might be sustainable for many years. An additional 3,000 to 6,000 acres of irrigation, over current estimates, would not be implausible on the basis of limited mining alone. The possibility of further

development, or limited mining of water would have to be considered on a case by case basis. Such development would likely occur in carefully monitored stages.

In Barnes County there are about 1,000 acre feet of water pumped annually by Barnes and Stutsman Rural Water districts. This amount would not be available for irrigation. However, because of other offsetting factors (discussed above) the final estimate of potentially irrigable land would probably not be greatly affected.

One factor in development that should be considered, is that most soils in Barnes County are conditionally irrigable. Much of the limitation is fineness of soil. In certain years, such as the years following the heavy precipitation of 1993, high water tables and ponded water in low areas could curtail irrigation. However, such large precipitation is not characteristic of the normal climate of Barnes County, and should be considered exceptional. In Barnes County, further expansion might prove to be limited by availability of suitable soil rather than by water limitations.

IRRIGATION DEVELOPMENT FROM SURFACE WATER

There are currently about 500 acres (548 acres) permitted for irrigation using surface water in Barnes County. The sole surface water source is the Sheyenne River. Actual use from 1991 through 1993 varied from as little as 204 acres to as much as 330 acres. Except for possible enhanced use of spring flows through artificial reharge, the waters of the Sheyenne River are already heavily allocated, and reliable supplies for increased summer use are not available. **The current water permit allocation of about 500 acres is used to estimate the total potential irrigation development using surface water in Barnes County.**

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT

Approximately 9,000 acres of potential irrigation, 8,500 acres from ground water and 500 acres from surface water, appears to be available for irrigation use in Barnes County. This estimate is likely conservative. Up to 4,000 additional acres might be available if land use is optimized, and 3,000 to 6,000 acres of additional development might be feasible under conditions of limited mining of water in the Spiritwood aquifer. Consideration of such additional expansion would have to proceed in carefully monitored stages.

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Potential Irrigation Development in Burleigh County, North Dakota

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT FOR BURLEIGH COUNTY

There are fourteen aquifers in Burleigh County which provide water for potential irrigation development. About 34,000 acres overlying these aquifers have soils classified as irrigable or conditionally irrigable, have slopes of less than 3 %, are free from substantial surface and subsurface drainage requirements, and lie in parcels of sufficient size for irrigation. In this study, estimates of potentially irrigable land are based on total land classified as irrigable, multiplied by a contingency factor of 1/2 to account for potential error, and land owner preferences regarding development. The contingency factor is also intended to lend a conservative bias to this report. Application of the contingency factor results in an estimate of at least 17,000 acres of irrigable land overlying aquifers in Burleigh County.

Water quality for irrigation varies widely, ranging from 0 to 80 % of ground water sampled that is of suitable quality for irrigation, based on the criteria of this study. Estimates of long-term sustainable yield indicate that sufficient water for about 6,000 acres of irrigation is possible on a long-term basis. After considering both land and water limitations, about 6,000 acres of irrigation would be potentially available for irrigation development using ground water.

The only substantial surface water source available for Burleigh County is the Missouri River. There is sufficient irrigable soil within reasonable distance of the Missouri River to allow for approximately 60,000 acres of irrigation. Under optimal conditions more might be irrigated.

Summing irrigation development estimates for both ground water and surface water, and subtracting to account for overlapping development (land counted for both ground-water and surface-water source development) results in a final estimate of **at least 65,000 acres for potential irrigation development in Burleigh County.** Estimates of potential irrigation development in this report compare with a total of 17,220 acres currently permitted for irrigation in Burleigh County.

POTENTIAL IRRIGATION DEVELOPMENT IN BURLEIGH COUNTY NORTH DAKOTA

The purpose of this report (chapter) is to provide an evaluation of land and water available for potential irrigation development in Burleigh County. Methods of assessment used in this report were designed to provide a conservative estimate. These methods were described in a previous introductory section. It is emphasized that the findings of this report are based on general information. They are preliminary in nature, and they should not be used for individual project planning without further local in-depth analysis. For the sake of continuity in computation, data on computation tables are provided to the nearest digit. However, this should not lead to the conclusion that this report can estimate acreage with such a high level of precision. **In the text of this report, the final summary estimates resulting from table computations are rounded to the nearest 500 acres.** These final rounded numbers reflect more appropriately the general character of these estimates.

Current Irrigation Development

In Burleigh County, there are currently 103 irrigation permits approved for 17,220 acres. Actual water use from 1991 through 1993 varied from as little as 2,939 acres to a maximum of 7,275 acres. 11,099 acres are permitted for irrigation using ground water (Table 1). Actual irrigation using ground water varied from 1,024 to 4,116 acres from 1991 through 1993. Permits for 6,394 acres have been approved for surface-water irrigation. Most of the surface-water permits (5,203 acres) are for use of Missouri River water. Actual use of Missouri River water varied from 1,758 acres to 3,060 acres during the period from 1991 through 1993. In addition, 142 acres are permitted for irrigation from Apple Creek, and 1,049 acres are permitted for irrigation from smaller streams and tributaries of major sources. Most irrigation from smaller tributaries consists of water-spreading on hay land in spring, and would not provide a reliable supply of summer irrigation water for irrigation of high value crops.

IRRIGATION DEVELOPMENT FROM GROUND WATER

Assessment of potential irrigable land in this report will not be limited to, or based on actual current water permits, or on current actual irrigated acreage. Rather it will be based on evaluation of the water and soil resource. In Burleigh County fourteen aquifers have been identified as potential sources for irrigation. These are listed on Table 2. There are two possible limiting factors affecting potential irrigation development using ground water. These are (1) irrigable land within practical

Table 1. Summary of current water permit allocations, and current water use in Burleigh County, ND.

WATER SOURCE	PERMITED LAND (ACRES)	IRRIGATED ACRES IN 1991	IRRIGATED ACRES IN 1992	IRRIGATED ACRES IN 1993
Ground Water	11,099	4,120	3,332	1,024
Surface Water	6,394			
Missouri River	5,203	3,060	2,987	1,758
Apple Creek Mainstem	142	91	125	77
Apple Creek Non-Mainstem	1,049	35	49	80

Table 2. Resources for potential irrigation development in Burleigh County, ND. ECE is the electrical conductivity of water; SAR is the sodium adsorption ratio of water; and Boron is the concentration of boron in water. Potential irrigable acres based on water limitations (column 8) are calculated by multiplying the total acreage (column 7) by the recharge coefficient coefficient in column (6) as described in the text, and by adjusting for water quality (column 5). Land mapped in irrigable soils series, and having a slope of less than 3% (column 10) is calculated from land area mapped in irrigable associations overlying the aquifer (column 9), adjusted for the proportion of the association attributed to soils of irrigation suitable series, and by an adjustment factor (0.46) accounting for slopes greater than 3%. The final estimate of potential irrigation development is half of column 10. **Bold type** indicates most limiting estimate of potential irrigation, used in final estimates of potential irrigation dev elopment. (c) indicates a confined aquifer, (u) is an unconfined aquifer, and (c/u) is a variably confined and unconfined aquifer. † Indicates that confinement is deep (> 50 ft. of overburdon).

(1) WATER SOURCE	(2) ECE %<1500 µS/cm	(3) SAR %< 6	(4) BORON %<2 mg/L	(5) WATER QUALITY COEFFICIENT	(6) RECHARGE COEFFICIENT	(7) AREA OVERLYING AQUIFER acres	(8) POTENTIAL IRRIGABLE ACRES-WATER LIMIT acres	(9) LAND MAPPED IN IRRIGABLE ASSOCIATIONS acres	(10) LAND MAPPED IN IRRIGABLE SOIL SERIES, SLOPE < 3% acres	(11) POTENTIAL IRRIGABLE SOIL OVERLYING AQUIFER acres
Apple Creek (Lower) -c	99	60	90	0.60	0.1	13,427	**806**	12,629	3,845	1,743
Apple Creek (Upper) -c/u	60	35	85	0.35	0.17	13,959	**831**	13,319	3,676	1,838
Bismarck	60	90	100	0.60	0.1	10,537	**632**	10,537	3,877	1,939
Burnt Creek	25	90	100	0.25	0.1	6,765	**169**	4,205	193	97
Glenview -c/u	?	20	?	0.20	0.17	2,116	72	2,116	778	389
Glencoe Channel -c	20	4	70	0.04	0.1	13,437	54	7,517	2,047	1,037
Long Lake -c	80	30	95	0.30	0.1	29,639	**889**	18,279	5,044	2,522
McKenzie-c	40	10	90	0.10	0.1	31,219	**312**	24,499	1,126	563
North Burleigh	100*	100*	100	0.50	0.1	11,441	**572**	11,441	4,210	2,105
Painted Woods	100*	100*	100	0.50	0.1	12,001	**600**	10,881	2,502	1,251
Random Creek -c	?*	?*	?*	0.5	0.1	6,666	**333**	6,666	1,839	920
Soo Channel -c†	99	80	95	0.80	0.05	9,078	**363**	7,318	1,683	842
Wagonsport -c/u	25	?	100	0.25	0.17	2,147	91	2,147	790	395
Wing Channel -c	100*	100*	100	0.50	0.1	9,652	**482**	5,812	2,139	1,069
Total	60	50	90	0.50		172,084	6,269	137,366	33,749	16,710

distance of the water source , and (2) available water of suitable quality in close proximity to irrigable land.

Total Irrigable Soils

If water were not limiting there would be ample irrigable land in Burleigh County. There are approximately 1,038,197 acres in Burleigh County. A soil association map (USDA-SCS 1974) is provided on Figure Bu-1. Of this, there are about 268,271 acres of Group 1 (irrigable without limitations, no drainage requirements) soils based on Burleigh County SCS soil survey tabulations. There are an additional 327,166 irrigable acres in the Group 2 category (irrigable with limitations, no drainage requirements). Usually the limitation is fineness of soil, which requires limited rates of water application. Soils requiring extensive surface or subsurface drainage are considered as non irrigable in this study. Thus, based on soil suitability alone, there are about 595,437 acres of potentially irrigable land. About half (46%, or 271,387 acres) of all soil classified in irrigable or conditionally irrigable series have slopes less than 3%.

Federal, state, and municipal land is excluded from the sum of potentially irrigable acres. Estimates of federal and state lands are approximately 17,390 acres, and municipal lands are estimated at 23,040 acres for Bismarck, and 5,760 acres for other towns in Burleigh County combined. The total of federal, state, and municipal land is 46,190 acres. About 26% of all land in Burleigh County is mapped to series classified as irrigable or conditionally irrigable. Adjusted for irrigability, about 12,000 acres of government land are excluded from the total of irrigable land, **resulting in a final estimate of about 259,000 acres** (259,387 acres) **that are irrigable or conditionally irrigable**, and have slopes of less than 3 %. A map of soil groups (irrigable, conditionally irrigable, and non irrigable) as defined for this study is provided on Figure Bu-2.

Estimates of total irrigable soils in Burleigh County by North Dakota State University (NDSU) as provided by Omodt (1982, written communication), are almost three times this estimate (627,000 acres). However, the criteria used in this study consist of a much more restrictive subset of the criteria used in the NDSU study. All soils requiring surface, or subsurface drainage, and all soils having slopes greater than 3% are excluded.

Estimates of Irrigable Soil Overlying Aquifers

The overall estimates of irrigable soils discussed above were taken from soil survey summary tables and were adjusted for slopes greater than 3%. Estimates of irrigation-suitable soil overlying aquifers were calculated by integrating the areas of mapped soil associations within mapped aquifer boundaries (Table 2, column 9). Soil association area was further adjusted by the fraction of the association attributed to irrigable soil series within the association. Soil series do not account for the

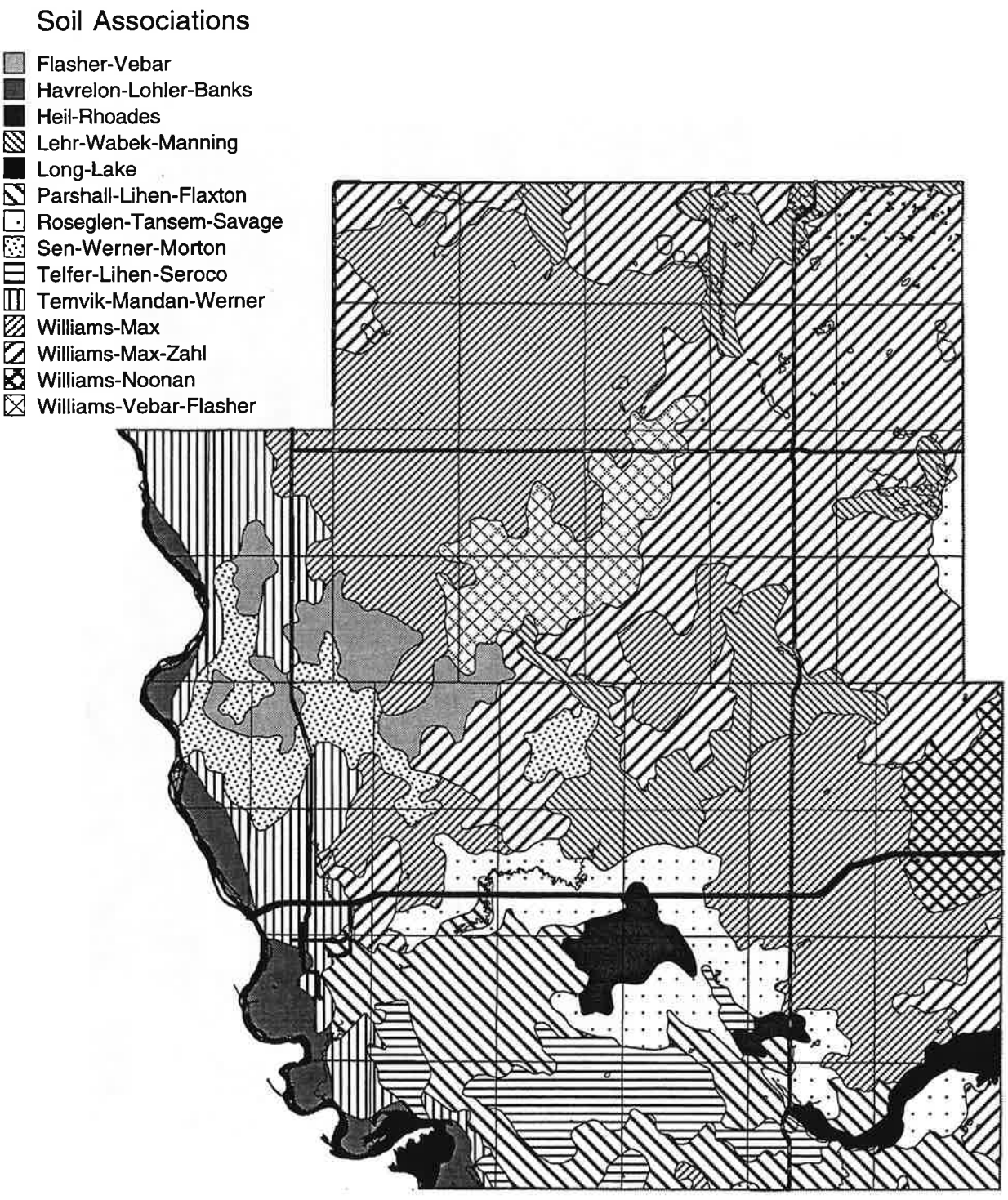

Figure Bu-1. Soil association map of Burleigh County ND. (From Burleigh County Soil Survey, USDA-SCS 1974).

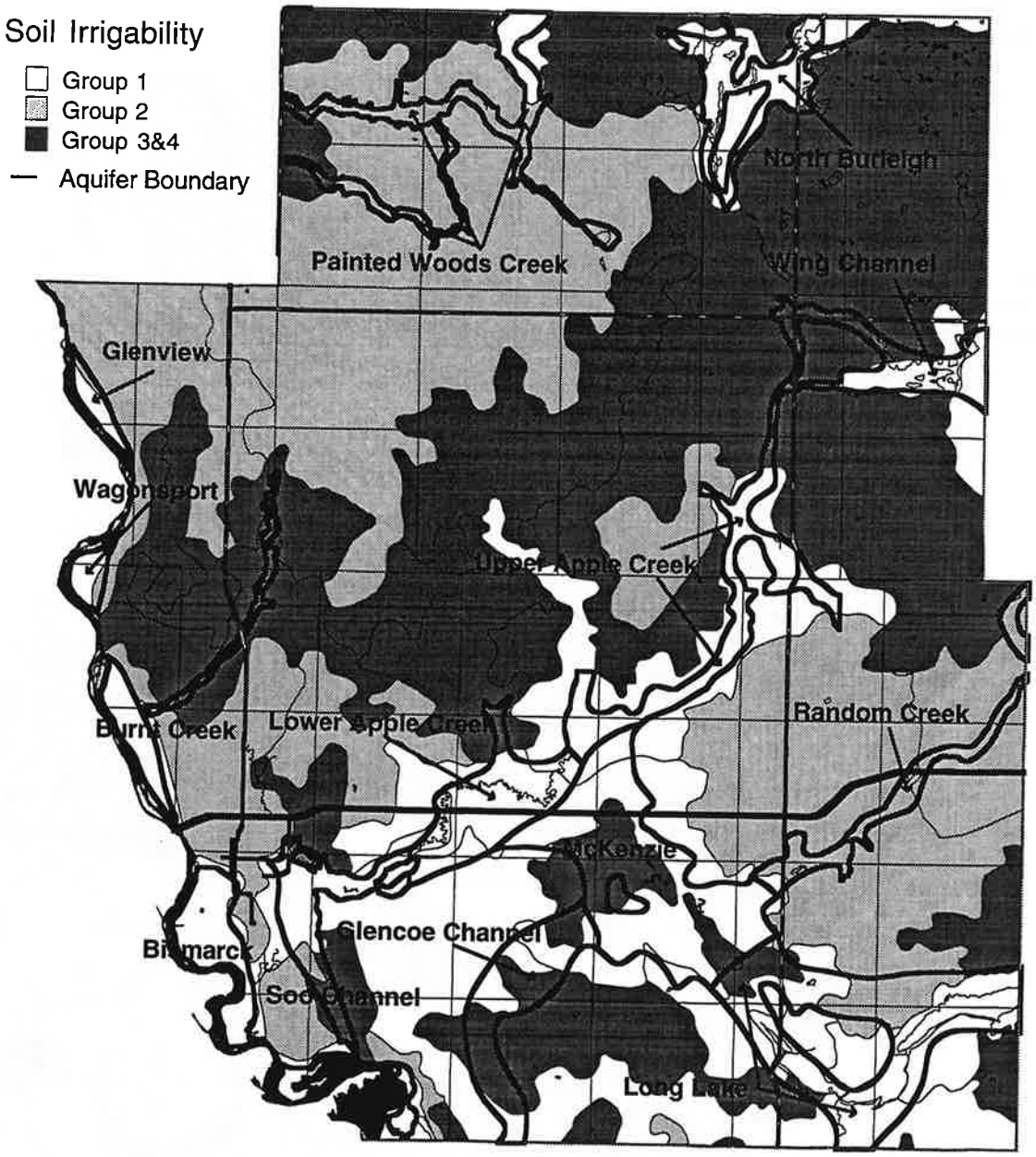

Figure Bu-2. Map of boundaries of aquifers in Burleigh County (From Larson, 1987).

fraction of the soil series of excessive slope, so a further adjustment was made for the series fraction having slope of 3% or less. The Burleigh County soil summary table data indicated that about 46 % of soils considered irrigable by association alone had acceptable (less than 3 %) slopes (Table 2, column 10, adjusted for slope and series). Finally, a contingency factor of 1/2 was a applied to account for error, interaction of soil and water suitability, and land use preference. Results in Table 2, column 11, indicated that **about 17,000 acres** (16,710 acres) **of land overlying aquifers would be considered as potentially irrigable based on soil suitability alone.**

Irrigable Land Overlying Aquifers Based on Water Supply Limitations

Supplies of water suitable for irrigation are limited in most aquifers. Estimates of water available for potential irrigation development are based on an estimated recharge 0.3 inches per year for deep confined aquifers in glacial till, 1.2 inch per year for shallow confined aquifers, 2 inches per year for aquifers that are partly confined, and partly unconfined, and 4 inches per year for unconfined aquifers. Irrigable acreage for each aquifer is then calculated by assuming an average irrigation use of 12 inches per acre per year. The recharge coefficient is the estimated recharge divided by the 12-inch use estimate. Recharge coefficients calculated for 0.3, 1.2, 2.5, and 4 inches are 0.025, 0.1, 0.17, and 0.33, respectively.

Almost all of the aquifers in Burleigh County are confined. However, the thickness of confining layers varies. Potential irrigated acreage was computed by multiplying the total area overlying each unconfined aquifer (Table 2, column 7) by the assigned recharge coefficient (Table 2, column 6).

A further limitation on water supply for irrigation is water quality. Probability plots for electrical conductivity (ECE), sodium adsorption ratio (SAR), and boron were graphed for all water samples in the North Dakota State Water Commission data base, for each aquifer (Table 2, columns 2, 3, and 4). Estimated sustainable yield was multiplied by the most limiting fraction of suitable water based on these three chemical parameters (Table 2, column 5). Aquifers having inadequate data were either grouped with other nearby aquifers, or were adjusted using fractions obtained from probability plots for data from all aquifers in Burleigh County. Results of these computations (total acreage overlying the aquifer multiplied by recharge and water quality factors) are shown on Table 2, column 8. **A total of about 6,000 acres** (6,269 acres) **was estimated as potentially irrigable using ground water, based on water supply limitations in Burleigh County.**

Potential Irrigation Development from Ground Water in Burleigh County

The most limiting factor in Table 2 [water limiting (column 8); or soil limiting (column 11)] is used to estimate potential irrigation development from each aquifer in Burleigh County. For all

aquifers, a long-term sustainable water supply of suitable quality is most limiting (column 8). Parcels of land having less than one quarter section are excluded from the total. **About 6,000 acres** (6,052 acres) **are estimated as having potential for irrigation development in Burleigh County.** This compares with about 11,000 acres currently permitted for irrigation from ground water, and a current actual use of 1,000 to 4,000 acres (Table 1).

Additional Comments

Additional factors should be considered in evaluating potential for irrigation development from ground water in Burleigh County. Estimates for potential development are based on estimates of sustainable yield for an indefinite period. In some cases a reasonable and limited level of mining might be allowable where there is large aquifer storage. In such cases additional water withdrawal might be possible for many years. This possibility would have to be evaluated on an individual aquifer basis.

On the other hand, low water quality coefficients (4 to 50 %) in many aquifers indicate that finding water of suitable quality may be a problem. Low water quality indicates that large tract development using ground water is not likely to occur. Rather, a process of gradual development of small tracts would be more likely. The fact that estimates made in this report are less than current permit allocations may be due to the conservative bias of this report. However, it may be due partly to current irrigation using waters considered to be of inadequate quality by standards of this report.

Finally, the reader is cautioned that the computation methods are general in nature, and for any given aquifer may be overly generous, or excessively limited. To a certain degree, such variances in estimation should cancel in the overall evaluation of the county. Actual irrigation potential for a specific aquifer could only be determined through detailed local investigation, and through the ongoing process of assessment which occurs during the implementation of actual irrigation development.

IRRIGATION DEVELOPMENT USING SURFACE WATER

Surface water sources in Burleigh County include the Missouri river, lakes, and smaller tributaries of the Missouri River. Of these the Missouri River represents the only large potential water supply. There are currently about 5,200 acres of approved water use for irrigation from the Missouri river mainstem (Table 1). Smaller tributaries, with the exception of Burnt Woods Creek, have limited and ephemeral supplies of water. 142 acres have been approved for irrigation from Apple Creek. However, Apple Creek now has a moratorium on further permits, and further development from this source seems unlikely in the near future. Approved irrigation from non mainstem Missouri and Apple

Creek sources in Burleigh County is about 1,050 acres. However, because many of the non mainstem sources are ephemeral and would not be reliable sources in dry years, they are excluded from consideration for potential development. Lakes are also excluded because of the complexities involved with lake hydrology and because of competing recreational and wildlife interests. While some lake waters would likely be available for use, they would have to be considered as individual cases. Lakes should not be considered as a potential large source of water in Burleigh County. .

The case of Painted Woods Creek requires further consideration. Under natural conditions Painted Woods Creek is ephemeral during the summer. However, since 1984 Painted Woods Creek has been the carrier of return flows from the McClusky Canal to the Missouri River. A probability plot of stream flow data beginning in 1984 indicates that about 95% of the time daily July flows averaged 20 cfs or above. While some of this water may be available for appropriation, the current management plan for the McClusky Canal does not include provisions for reliable irrigation supplies from return flows. Painted Woods Creek is thus excluded from consideration.

Irrigation From the Missouri River

The Missouri River is by far the largest potential source of irrigation water in central North Dakota. From the standpoint of water quantity, it is treated in this study as unlimited (other factors are likely to be limiting). Access is considered to be a major limitation. Much of the land near the Missouri River is federally owned. Moreover, elevations and subsequent lift for moving water to potential sites can be considerable. Irrigation is most feasible where lift from the river is least. It is also most feasible where irrigation use can begin near the river, so that financial return on the cost of conveyance facilities can be optimized. The criterion used in this study will be approximately 260 foot of maximum lift, and ability to irrigate within five miles of the river. Preference is also given to lands that are accessible to the river in non reservoir reaches, because of the difficulty in design of water retrieval facilities operable over the range of reservoir fluctuations. However, reservoir sources are not ruled out. Access problems are considered to be primarily engineering problems, and are relegated to later more detailed studies. Potential irrigable land using Missouri River water is summarized on Table 3.

There are two potential irrigation development tracts near the Missouri River in Burleigh County. The first tract consists of parcels of land immediately contiguous to the Missouri River. The second tract consists of a substantial inland parcel accessible from the Missouri River. Locations of both tracts are shown on Figure Bu-3. Contiguous lands are a minor portion of the total irrigable land. Total contiguous acres were estimated at 11,444 acres. Applying an adjustment of 1/2 **about 5,500 acres** (5,722 acres) **of potential irrigation land contiguous to the Missouri River is estimated.**

Table 3. Potentially irrigable land in Burleigh County, using Missouri River water.

WATER SOURCE	ECE %<1500 µS/cm	SAR %< 6	BORON %<2 mg/L	WATER USE COEFFICIENT	POTENTIAL IRRIGABLE ACRES	ADJUSTED POTENTIAL IRRIGABLE ACRES (1/2 adjusted)
CONTIGUOUS LAND	100	100	100	1.00	11,444	5,722
INLAND TRACT	100	100	100	1.00	108,840	54,420
						60,142

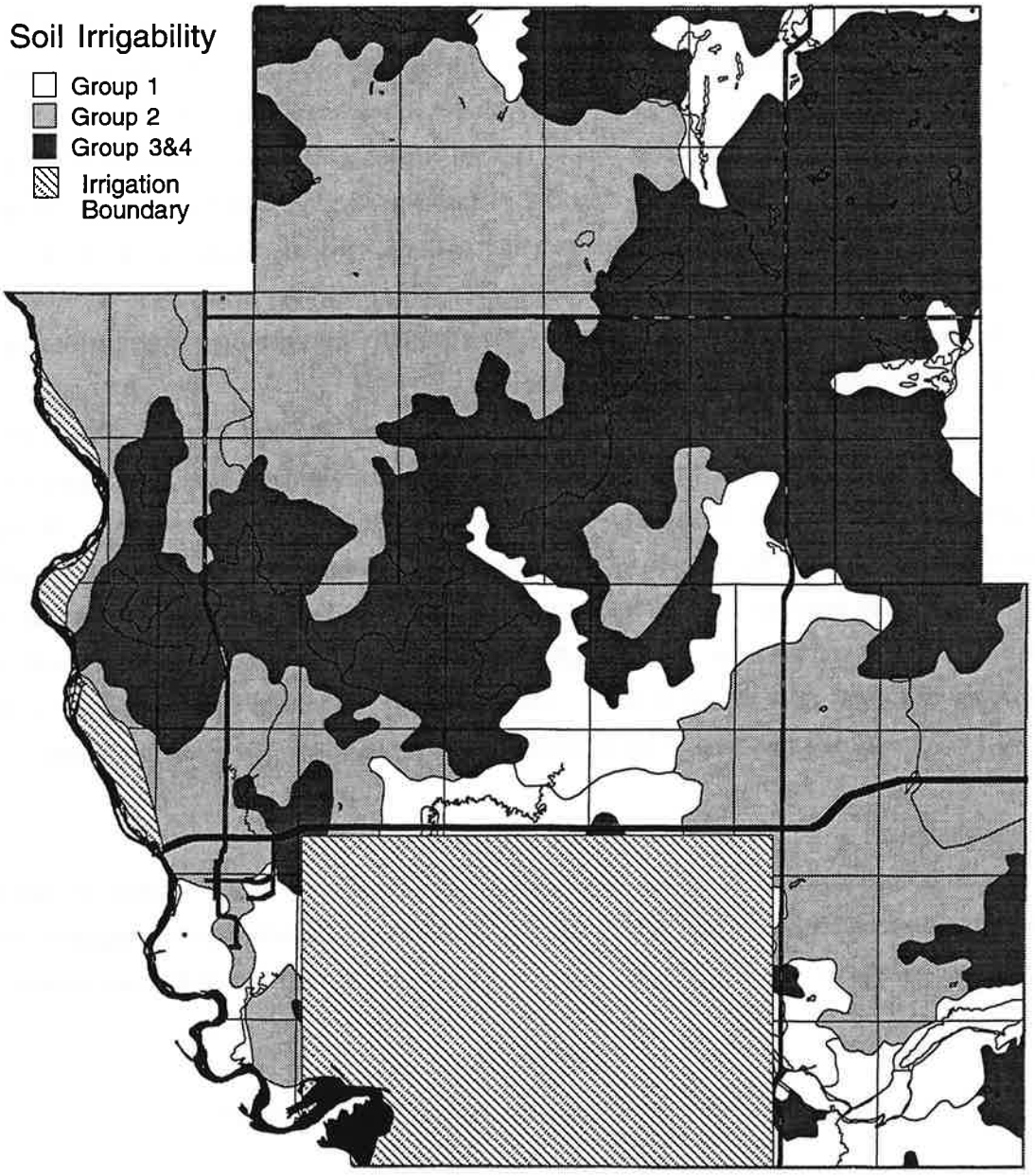

Figure Bu-3. Map of tracts of land in Burleigh County that may be developed for irrigation using water from the Missouri River.

Inland development from the river is limited by both distance and elevation in northern Burleigh County. However, there is one large tract of potentially irrigable land that is apparently accessible from the river in southern Burleigh County. Access to the river is possible at sites in T137, R80, S14, and T137, R79, S16, and access to the reservoir appears to be feasible in T136, R79, S1. Elevation criteria are acceptable for a large distance inland from these points, and irrigation appears to be feasible within a couple of miles of the river. Moreover, this area corresponds to a large tract of Group 1 (irrigable without limitation) land, mostly located between McKenzie, Menoken, and Moffit, and with some land extending north of Interstate 94. For sake of practical limitation, inland boundaries are set at Interstate 90 in the North and at Highway 83 in the east. The south boundary is the Emmons County line, and the west boundary is the first section line inland from the Missouri River. However, from the soil suitability standpoint development would be possible farther north and farther southeast from the designated area (Figure Bu-3).

The delineated potential development area in southern Burleigh County (Figure Bu-3) consists of approximately 101,052 acres of Group 1 (irrigable without limitation) soil. Applying an adjustment factor of 1/2, the delineated area contains about 50,500 acres of Group 1 land. Group 2 (irrigable with limitations) is 7,839 acres. Applying the 1/2 adjustment factor allows for about 3,920 acres of conditionally irrigable land. **The total estimate of potentially irrigable land in the southern development area is about 54,500 acres** (54,420 acres)**.** Combined with the smaller tracts along the river in the northern part of Burleigh County, **a total of about 60,000 acres** (60,142 acres) **of land would be potentially irrigable from the Missouri River.**

Additional Comments

The 60,000 acre potential development estimate for Missouri River water is based on static lift limitations, and on an arbitrary limitation of distance from the river. Suitable soil for irrigation is not limited, and if economic conditions warranted, the potential for development could be much greater.

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT

In Burleigh County there is ample (277,860 acres) soil in irrigable and conditionally irrigable classes, which do not require surface or subsurface drainage, and which have slopes of 3% or less. Of this total, about 82,122 acres are classified as irrigable without condition. However, only 33,749 acres of this land overlie aquifers, after adjustment for excessively sloped land. The limitation of sustained yield, and water quality provides for an estimated 6,000 acres of potential irrigation development using ground water.

The major water resource for development is the Missouri River, which has excellent water quality for irrigation. In areas approachable from the Missouri River, there are about 60,142 acres of potentially irrigable land. Of this about 5,722 acres may be available in tracts along the Missouri River in northern Burleigh County, and 54,400 acres of potentially irrigable soils may be usable in a single large tract in the southwest and south central parts of Burleigh County. The large tract contains about 50,500 acres of soil that are irrigable without condition. The remainder is conditionally irrigable without required drainage.

There is some overlap of potential irrigation from wells and irrigation from the Missouri River. An approximate overlap of about 1,300 acres was estimated. **Adjusting for this overlap, it would be estimated that a total of about 65,000 acres would be available for potential irrigation from all sources in Burleigh County.**

REFERENCES

USDA-SCS. 1974 . Burleigh County Soil Survey.

Omodt, Hollis W. 1982. Irrigability of soil mapping units by county. Written Communication to Larry Knudtson, January 4, 1992.

Randich, P.G., and J.L. Hatchett. 1966. Geology and Ground Water Resources in Burleigh County, North Dakota: Part III, Ground Water Resources. Bulletin 42. North Dakota State Water Conservation Commission. Bismarck, ND.

Potential Irrigation Development in Eddy County, North Dakota

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT FOR EDDY COUNTY

There are eleven aquifers in Eddy County which provide water for potential irrigation development. About 21,000 acres overlying these aquifers have soils classified as irrigable or conditionally irrigable, have slopes of less than 3 %, are free from substantial surface and subsurface drainage requirements, and lie in parcels of sufficient size for irrigation. In this study, estimates of potentially irrigable land are based on total land classified as irrigable, multiplied by a contingency factor of 1/2 to account for potential error, and land owner preferences regarding development. The contingency factor is also intended to lend a conservative bias to this report. Application of the contingency factor results in an estimate of at least 10,000 acres of irrigable land overlying aquifers in Eddy County.

Water quality for irrigation is variable. About 70% of water samples taken from the Central Eddy and New Rockford aquifers are of suitable quality for irrigation, based on the criteria of this study. Other aquifers have as much as 100 percent water of suitable water. Estimates of long-term sustainable yield indicate that sufficient water for about 11,000 acres of irrigation is possible on a long-term basis. There is little potential for expanded irrigation using surface water in Eddy County.

Potential irrigation development is estimated by summing the most limiting resource (irrigable land or water) for each aquifer. **Results indicate that development of at least 4,000 acres for irrigation should be feasible in Eddy County.** Estimates of potential irrigation development in this report compare with a total of 2,624 acres currently permitted for irrigation in Eddy County. This estimate is likely conservative, and it would not be implausible that some additional acres of irrigation might be developed in carefully monitored stages.

POTENTIAL IRRIGATION DEVELOPMENT IN EDDY COUNTY NORTH DAKOTA

The purpose of this report (chapter) is to provide an evaluation of land and water available for potential irrigation development in Eddy County. Methods of assessment used in this report were designed to provide a conservative estimate. These methods were described in a previous introductory section. It is emphasized that the findings of this report are based on general information. They are preliminary, and they should not be used for individual project planning without further local in-depth analysis. For the sake of continuity in computation, data on computation tables are provided to the nearest digit. However, this should not lead to the conclusion that this report can estimate acreage with such a high level of precision. **In the text of this report, the final summary estimates resulting from table computations are rounded to the nearest 500 acres.** These final rounded numbers reflect more appropriately the general character of these estimates.

In Eddy County there are currently 22 irrigation permits for a total of 2,624 acres. Actual water use varies. Between 1991 and 1993 largest irrigated acreage was 2,162 in 1992. Least irrigation (1,296 acres) occurred in 1993, which was an extremely wet year.

IRRIGATION DEVELOPMENT FROM GROUND WATER

Assessment of potential irrigable land in this report will not be limited to or based on actual current water permits, or on current actual irrigated acreage. Rather it will be based on evaluation of the water and soil resource. In Eddy County eleven principal aquifers have been identified as potential sources for irrigation. These are listed on Table 1. There are two possible limiting factors affecting potential irrigation development using ground water. These are (1) irrigable land within practical distance of the water source , and (2) available water of suitable quality in close proximity to irrigable land.

Total Irrigable Soils

According to a study conducted by North Dakota State University (NDSU) there are about 410,678 total acres in Eddy County. After exclusion of mapped water bodies there are approximately 393,550 acres of soil in Eddy County , of which 316,969 are irrigable or conditionally irrigable (Omodt, written communication, 1982). Of this about 63 %, is classified as conditionally irrigable because of slope, drainage requirements, or slowness of internal drainage.

Table 1. Resources for potential irrigation development in Eddy County, ND. EC is the electrical conductivity of water; SAR is the sodium adsorption ratio of water; and Boron is the concentration of boron in water. Potential irrigable acres based on water limitations (column 8) are calculated by multiplying the total acreage (column 7) by the recharge coefficient coefficient in column (6) as described in the text, and by adjusting for water quality (column 5). Land mapped in irrigable soils series, and having a slope of less than 3% (column 10) is calculated from land area mapped in irrigable associations overlying the aquifer (column 9), adjusted for the proportion of the association attributed to soils of irrigation suitable series, and by an adjustment factor (0.76) accounting for slopes greater than 3%. The final estimate of potential irrigation development is half of column 10. **Bold type** indicates most limiting estimate of potential irrigation, used in final estimates of potential irrigation dev elopment. c indicates confined aquifer, u indicates unconfined aquifer, and c/u indicates variably confined and unconfined aquifer.

(1) WATER SOURCE	(2) ECE %<1500 µS/cm	(3) SAR %< 6	(4) BORON %<2 mg/L	(5) WATER QUALITY COEFFICIENT	(6) RECHARGE COEFFICIENT	(7) AREA OVERLYING AQUIFER acres	(8) POTENTIAL IRRIGABLE ACRES-WATER LIMIT acres	(9) LAND MAPPED IN IRRIGABLE ASSOCIATIONS acres	(10) LAND MAPPED IN IRRIGABLE SOIL SERIES, SLOPE < 3% acres	(11) POTENTIAL IRRIGABLE SOIL OVERLYING AQUIFER acres
Central Eddy -c/u	-	-	-	0.7**	0.21	10,796	**1,587**	7,756	3,536	1,768
Cherry Lake -c/u	90	70	90	0.7	0.21	1,747	256	1,025	506	**253**
Johnson Lake -c	-	-	-	0.6**	0.10	4,643	**278**	4,323	2,233	1,116
New Rockford -c†	75	75	100	0.75	0.05	32,761	**1,228**	25,199	8,043	4,021
Northwest Eddy -c/u	100	100	100	1	0.21	1,544	324	1,224	632	**316**
Rosefield -c/u	95	97	97	0.97	0.17	3,609	**595**	3,609	1,727	863
Sheyenne Channel -c	-	-	-	1.0**	0.17	843	143	843	128	64 @
Sheyenne Village -u	-	-	-	0.75**	0.33	581	143	581	264	**132**
Spiritwood -c†	90	50	98	0.5	0.05	3345	83	2,225	1,014	507
Tokio -u	100	100	100	1	0.33	677	223	677	308	154 @
Warwick Aquifer -u	100	100	100	1	0.33	19,564	6,456	5,567	2,327	1,163 @
Total						80,110	11,316	53,029	20,718	10,357

* Sparse data.
** Insufficient data. Water quality coefficient based on other nearby aquifers.

The classification used in this report is a much more restrictive subset of that used in the NDSU study. A soil association map (USDA-SCS, 1977) is provided on Figure Ed-1. All soils requiring extensive surface or internal drainage are excluded from consideration, and all soils having slopes of more than 3 % are also excluded. Using the criteria of this study, about 132,361 acres are classified as Group 1 (irrigable without limitations, slope less than 3 %) soils based on Eddy County SCS soil survey tabulations. There are an additional 17,709 irrigable acres in the Group 2 category (irrigable with limitations). Thus, based on soil suitability alone, there are about 150,070 acres of potentially irrigable land.

All federal, state, and municipal land is excluded from the potentially irrigable acres. There are about 16,175 acres of state and federal land, and about 2,560 acres of municipal land, for a total of about 18,735 acres of government land. About 38 % of all land in Eddy County is classified as irrigable according to standards of this study. Applying this proportion to government land gives 7,119 acres of excluded land that might be considered irrigable. After subtracting estimated irrigable government land, approximately **143,000 acres** (142,950 acres) **would be considered to be potentially irrigable based on soil factors alone.** A map of soil Groups (irrigable, conditionally irrigable, and non irrigable) as defined for this study is provided on Figure Ed-2. The reader should be aware that there is substantial non irrigable land included with the predominantly irrigable Heimdal, Emrick, Fram association, which accounts for the relatively large proportion of the map shown to be in Group 1.

Estimates of Irrigable Soil Overlying Aquifers

The overall estimates of irrigable soils discussed above were taken from soil survey summary tables and were adjusted for slopes greater than 3%. Estimates of irrigation-suitable soil overlying aquifers were calculated by integrating the areas of mapped soil associations within mapped aquifer boundaries. Area mapped to soil associations considered to be predominantly irrigable were adjusted by the percent of land in individual soil series classified as irrigable within the association. In addition, irrigable series were adjusted to account for slopes greater than 3% using a factor of 0.76. Eddy County soil summary table data indicated that about 76 % of soils mapped in series considered irrigable, had slopes of less than 3 %. Finally, a 1/2 contingency factor was applied to all estimates of irrigable soil area. Results in Table 1, column 11, indicates that **about 10,000 acres** (10,357 acres) **of land overlying aquifers would be considered as potentially irrigable based on soil suitability alone**. Most of this land overlies the Central Eddy, Johnson Lake, New Rockford, and Warwick aquifers.

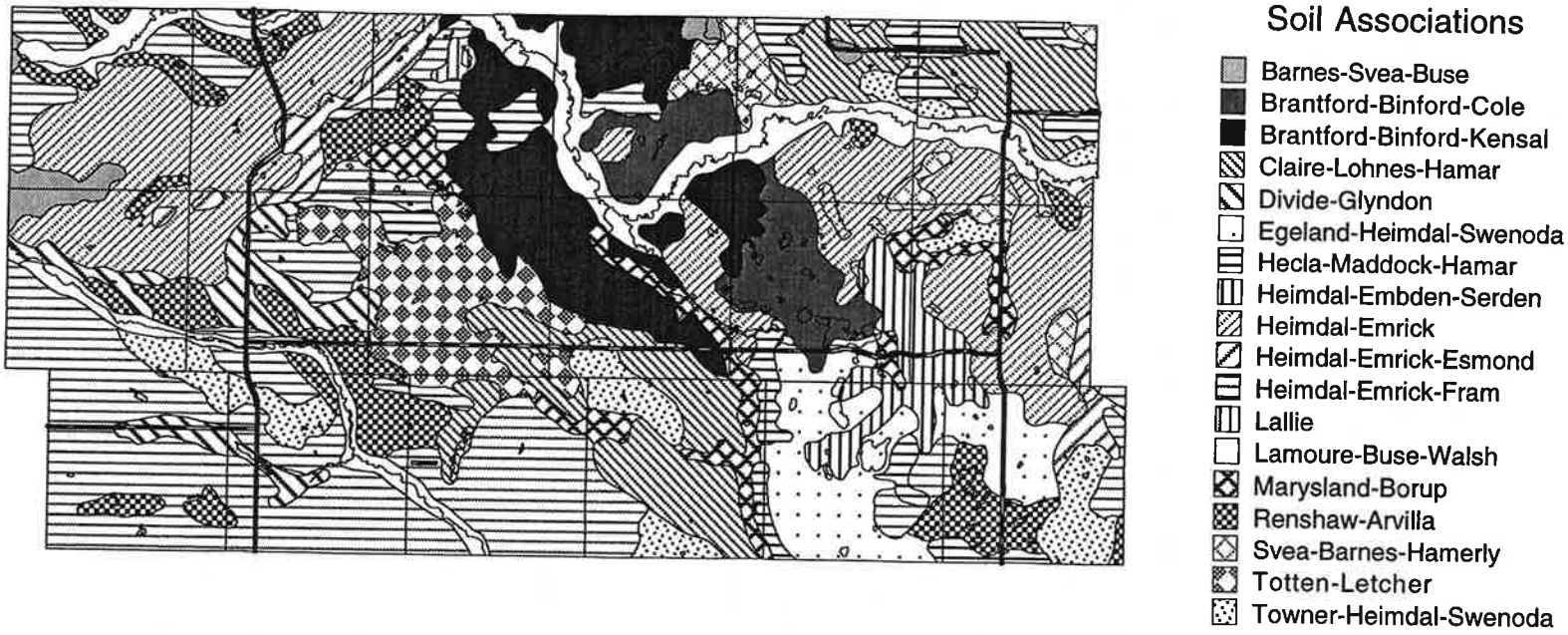

Figure Ed-1. Soil association map of Eddy County ND. (From Eddy County Soil Survey, USDA-SCS , 1977).

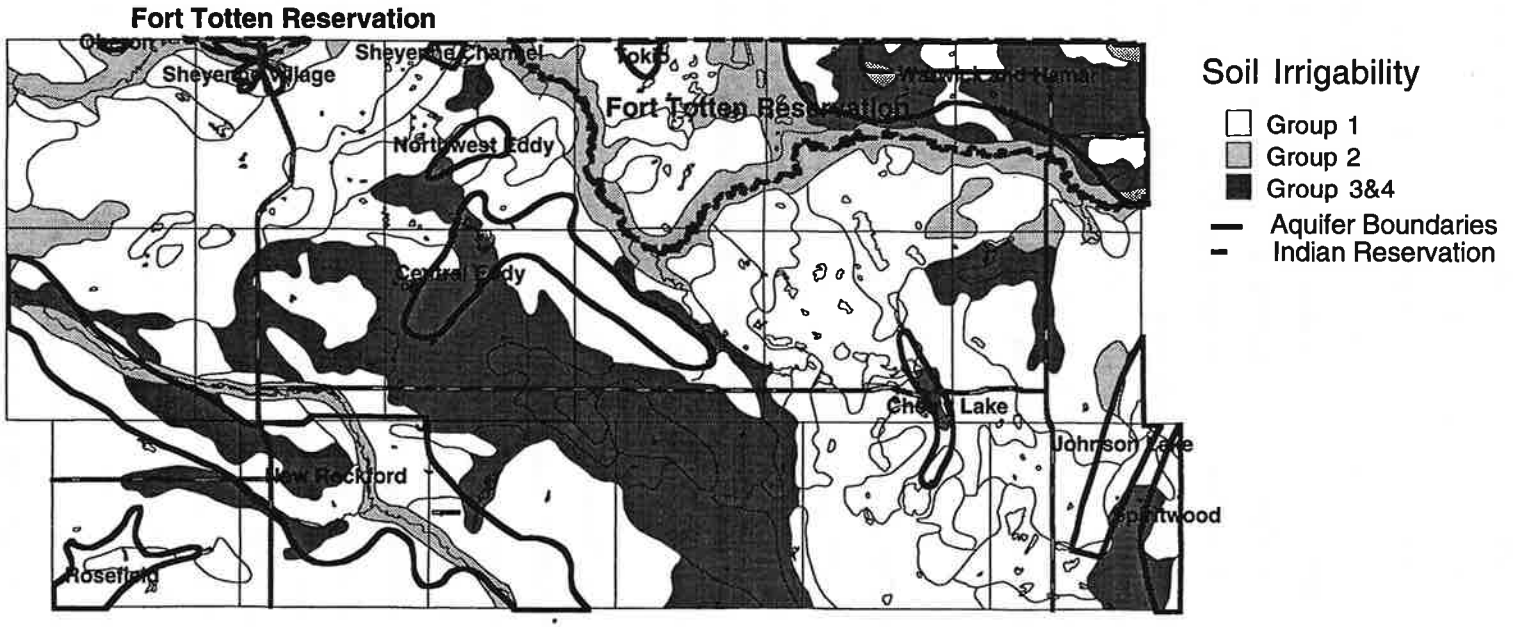

Figure Ed-2. Map of boundaries of the principal aquifers in Eddy County, ND. (From Trapp, 1968).

Potential Irrigation Development Over Aquifers Based on Water Supply Limitations

Ground-water resources in Eddy County have variable quality for irrigation use. Between 70 and 100 % of the ground water from aquifers considered on Table 1 are of suitable quality for irrigation. Water quality is evaluated on the basis of suitable electrical conductivity (ECE), sodium adsorption ratio (SAR), and Boron concentration (Table 1). Estimates of water available for potential irrigation are based on an estimated recharge of 0.3 inches per year for deeper confined aquifers in glacial till, 1.2 inches per year for shallow confined aquifers, 2.5 inches per year for aquifers that are partly confined, and partly unconfined, and 4 inches per year for unconfined aquifers. Irrigable acreage for each aquifer is then calculated by assuming an average of 12 inches per acre per year irrigation. The recharge coefficient is the estimated recharge divided by the 12-inch use estimate. Recharge coefficients calculated for 0.3, 1.2, 2.5, and 4 inches are 0.025, 0.1, 0.21, and 0.33, respectively. In some cases, depending on the aquifer, ranges of values between these coefficients are selected.

Irrigation acreage based on sustainable water use is further adjusted by the water quality coefficient, which is the probability of obtaining water suitable for irrigation in a given well (Table 1, column 5). The most limiting parameter (of ECE, SAR, Boron) is used to adjust for water quality. The resulting irrigable acreage estimate based on recharge and water quality is in Table 1, column (8). **About 11,000 acres** (11,316 acres) **are estimated as potentially irrigable, based on estimates of available water of suitable quality for irrigation.**

Potential Irrigation Development from Ground Water in Eddy County

The most limiting factor in Table 1 [water limiting (column 8); or soil limiting (column 11)] is used to estimate potential irrigation development from ground water in Eddy County. Parcels of land less than 130 acres are not included in the sum of potentially irrigable acres. Irrigation development from the Pipestem Creek and Juanita Lake aquifers is limited by available soil. Development from all other aquifers is limited by estimated sustainable yield. However, in most cases soil and water resources are fairly closely matched. **The sum of potentially irrigable acres based on the most limiting resource is about 4,000 acres** (4,136 acres). Most potential development estimates are water limited. For those that are soil limited, area estimates are still similar to water limits. Thus, the 1/2 contingency factor does not substantially change the overall acreage for potential irrigation development. This compares with about 2,517 acres already permitted for irrigation using ground water in Eddy County. Actual water use for irrigation between 1991 and 1993 varied from as little as 1,296 acres irrigated in 1993 to 2,085 acres irrigated in 1992.

The 4,000 acre estimate did not include 253 acres overlying the Cherry Lake aquifer, which is occupied by the Camp Grafton South Military Reservation. Also excluded from the total were 1,312

estimated available acres overlying the Warwick and Tokio aquifers, but within the confines of the Fort Totten Indian Reservation. Appropriate arrangements with tribal authorities may allow for development and irrigation of these lands as well.

Additional Comments

It is considered that the estimate of 4,000 acres of irrigation development is conservative, and that some additional development might be possible. Estimates were based on computations of sustained yield. Some additional development might be allowable on the basis of limited mining from large aquifers, and might be sustainable for many years without excessively depleting the aquifers. This, however, would have to be considered on a case by case basis, and should not be considered as a reliable estimate of available water.

IRRIGATION USING SURFACE WATER

There are currently 107 acres approved for irrigation using surface water in Eddy County. This includes minor amounts allocated from the James River (21 acres) and the Sheyenne River (86 acres). Total annual actual irrigation from 1991 through 1993 has usually been about 77 acres. Minimum recorded use was 0 acres in 1993. The James and Sheyenne Rivers are already heavily appropriated, and further irrigation use is unlikely. There are numerous small lakes, potholes, and sloughs in Eddy County. However, these are excluded as potential water sources because of the complexities involved with lake hydrology and because of competing recreational and wildlife interests. While some lake waters would likely be available for use, they would have to be considered as individual cases. Total current irrigation from surface water is insubstantial, and does not significantly effect the overall total of potential development.

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT

Approximately 4,000 acres of potential irrigation, all from ground water, appears to be available for development in Eddy County. Additional development might be feasible under appropriate conditions, but would likely have to be implemented in carefully monitored stages.

REFERENCES

Trapp, Henry. 1968. Ground-water Resources of Eddy and Foster Counties, North Dakota. County Ground-Water Studies 5, Part III. North Dakota State Water Commission. Bismarck, ND.

Omodt, Hollis W. 1982. Irrigability of North Dakota Soils, based on written communication to Larry Knudtson.

USDA-SCS. 1977. Soil Survey of Eddy County and parts of Benson and Nelson County, North Dakota.

Potential Irrigation Development in Emmons County, North Dakota

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT FOR EMMONS COUNTY

There are five aquifers in Emmons County which provide water for potential irrigation development. About 13,000 acres overlying these aquifers have soils classified as irrigable or conditionally irrigable, have slopes of less than 3 %, are free from substantial surface and subsurface drainage requirements, and lie in parcels of sufficient size for irrigation. In this study, estimates of potentially irrigable land are based on total land classified as irrigable, multiplied by a contingency factor of 1/2 to account for potential error, and land owner preferences regarding development. The contingency factor is also intended to lend a conservative bias to this report. Application of the contingency factor results in an estimate of at least 6,500 acres of irrigable land overlying aquifers in Emmons County.

Water quality for irrigation varies widely, ranging from 45 to 93 % of ground water sampled that is of suitable quality for irrigation, based on the criteria of this study. Estimates of long-term sustainable yield indicate that sufficient water for about 7,000 acres of irrigation is possible on a long-term basis. After considering both land and water limitations, about 6,000 acres of irrigation would be potentially available for irrigation development using ground water.

The only substantial surface water source available for Emmons County is the Missouri River. Two tracts of land that appear to be promising for irrigation development are the Horsehead Flats and Winona Flats tracts. In the Horsehead Flats tract there appears to be sufficient irrigable soil within reasonable distance of the Missouri River to allow for approximately 30,000 acres of irrigation. A previous study by the U.S. Bureau of Reclamation planned 18,000 acres for irrigation development in Horsehead Flats. In the Winona Flats tract there appears to be sufficient irrigable soil within reasonable distance of the Missouri River to allow for approximately 9,000 acres of irrigation. A previous study by the U.S. Bureau of Reclamation planned 4,600 acres for irrigation development in Winona Flats.

Summing irrigation development estimates for both ground water and surface water, and subtracting to account for overlapping development (land counted for both ground-water and surface-water source development) results in a final estimate of **at least 44,500 acres for potential irrigation development in Emmons County.** Estimates of potential irrigation development in this report compare with a total of 10,749 acres currently permitted for irrigation in Emmons County. If results of the U.S. Bureau of Reclamation preliminary project assessment for Horsehead Flats and Winona Flats is used as an estimate of potential irrigable land using Missouri River water, the total potential irrigation development would be 28,500 acres.

POTENTIAL IRRIGATION DEVELOPMENT IN EMMONS COUNTY NORTH DAKOTA

The purpose of this report (chapter) is to provide an evaluation of land and water available for potential irrigation development in Emmons County. Methods of assessment used in this report were designed to provide a conservative estimate. These methods were described in a previous introductory section. It is emphasized that the findings of this report are based on general information. They are preliminary in nature, and they should not be used for individual project siting without further local in-depth analysis. For the sake of continuity in computation, data on computation tables are provided to the nearest digit. However, this should not lead to the conclusion that this report can estimate acreage with such a high level of precision. **In the text of this report, the summary estimates resulting from table computations are rounded to the nearest 500 acres.** These final rounded numbers reflect more appropriately the general character of these estimates.

Current Irrigation Development

In Emmons County, there are currently 46 irrigation permits approved for 10,749 acres. Actual water use from 1991 through 1993 varied from as little as 4,270 acres to a maximum of 7,538 acres. 2,915 acres are permitted for irrigation using ground water (Table 1). Actual irrigation using ground water varied from 1,160 to 2,620 acres from 1991 through 1993. Permits for 8,073 acres have been approved for surface-water irrigation. Most of the surface-water permits (7,090 acres) are for use of Missouri River water. Actual use of Missouri River water varied from 3,070 acres to 4,568 acres during the period from 1991 through 1993. In addition, 935 acres are permitted for irrigation from smaller streams and tributaries.

IRRIGATION DEVELOPMENT FROM GROUND WATER

Assessment of potential irrigable land in this report will not be limited to, or based on actual current water permits, or on current actual irrigated acreage. Rather it will be based on evaluation of the water and soil resource. In Emmons County five aquifers have been identified as potential sources for irrigation. These are listed on Table 2. There are two possible limiting factors affecting potential irrigation development using ground water. These are (1) irrigable land within practical distance of the water source , and (2) available water of suitable quality in close proximity to irrigable land.

Table 1. Summary of current water permit allocations, and current water use in Emmons County, ND.

WATER SOURCE	PERMITED LAND (ACRES)	IRRIGATED ACRES IN 1991	IRRIGATED ACRES IN 1992	IRRIGATED ACRES IN 1993
Ground Water	2,915	2,620	2,470	1,160
Surface Water	8,073			
Missouri River	7,090	4,349	4,568	3,070
Non-Mainstem Permits	935	478	788	327

Table 2. Resources for potential irrigation development in Emmons County, ND. EC is the electrical conductivity of water; SAR is the sodium adsorption ratio of water; and Boron is the concentration of boron in water. Potential irrigable acres based on water limitations (column 8) are calculated by multiplying the total acreage (column 7) by the recharge coefficient coefficient in column (6) as described in the text, and by adjusting for water quality (column 5). Land mapped in irrigable soils series, and having a slope of less than 3% (column 10) is calculated from land area mapped in irrigable associations overlying the aquifer (column 9), adjusted for the proportion of the association attributed to soils of irrigation suitable series, and by an adjustment factor (0.50) accounting for slopes greater than 3%. The final estimate of potential irrigation development is half of column 10. **Bold type** indicates most limiting estimate of potential irrigation, used in final estimates of potential irrigation dev elopment. (c) indicates confined aquifer [less than 50 ft. overburdon], (u) is unconfined, and (c/u) is variably confined and unconfined.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
WATER SOURCE	EC	SAR	BORON	WATER QUALITY COEFFICIENT	RECHARGE COEFFICIENT	AREA OVERLYING AQUIFER	POTENTIAL IRRIGABLE ACRES-WATER LIMIT	LAND MAPPED IN IRRIGABLE ASSOCIATIONS	LAND MAPPED IN IRRIGABLE SOIL SERIES, SLOPE < 3%	POTENTIAL IRRIGABLE SOIL OVERLYING AQUIFER
	%<1500 µS/cm	%< 6	%<2 mg/L			acres	acres	acres	acres	acres
Braddock -c*	99	93	100	0.93	0.1	5,696	530	1,440	486	**243**
Cattail -c*	94	70	72	0.70	0.1	1,555	**109**	480	151	76
Long Lake -c/u	80	30	95	0.30	0.17	3,142	**160**	2,560	806	403
Strasburg -c/u	82	79	80	0.79	0.17	47,270	6,348	38,470	10,387	**5,193**
Winona -c*	78	45	59	0.45	0.1	4,576	**206**	4,000	1,260	630
Total	75	75	99	00.75		62,239	7,353	46,950	13,090	6,545

Total Irrigable Soils

There is ample irrigable land in Emmons County. There are approximately 1,038,197 acres in Emmons County. A soil association map (USDA-SCS, 1980) is provided on Figure Em-1. Of this, there are about 144,758 acres of Group 1 (irrigable without limitations, slope less than 3 %) soils based on Emmons County SCS soil survey tabulations. There are an additional 33,652 irrigable acres in the Group 2 category (irrigable with limitations). Usually the limitation is slope, or fineness of soil, which requires limited rates of water application. Soils requiring extensive surface or subsurface drainage are considered as non irrigable in this study. Thus, based on soil suitability alone, there are about 178,410 acres of potentially irrigable land. About half (44 %) of all soil classified in irrigable or conditionally irrigable series have slopes less than 3%.

Federal, state, and municipal land is excluded from the sum of potentially irrigable acres. Estimates of federal and state lands are approximately 35,399 acres, and municipal lands are estimated at 4,480. The total of federal, state, and municipal land is 39,878 acres. About 18 % of all land in Emmons County is mapped to series classified as irrigable or conditionally irrigable according to the criteria of this study. Adjusted for irrigability, about 7,357 acres of government land are excluded from the total of irrigable land, **resulting in a final estimate of about 171,000 acres** (171,052 acres) **that are irrigable or conditionally irrigable**, and have slopes of less than 3 %. A map of soil groups (irrigable, conditionally irrigable, and non irrigable) as defined for this study is provided on Figure Em-2.

Estimates of total irrigable soils in Emmons County by North Dakota State University (NDSU) as provided by Omodt (1982, written communication), are almost three times this estimate (558,000 acres). However, the criteria used in this study consist of a much more restrictive subset of the criteria used in the NDSU study. All soils requiring surface, or subsurface drainage are excluded, and all soils having slopes greater than 3% are excluded.

Estimates of Irrigable Soil Overlying Aquifers

The estimates of irrigable soils discussed above were taken from soil survey summary tables and were adjusted for slopes greater than 3%. Estimates of irrigation-suitable soil overlying aquifers were calculated by integrating the areas of mapped soil associations within mapped aquifer boundaries (Table 2, column 9). Soil association area was further adjusted by the fraction of the association attributed to irrigable soil series within the association. Soil series do not account for the fraction of the soil series of excessive slope, so a further adjustment was made for the series fraction having slope of 3% or less. The Emmons County soil summary table data indicated that about 44 % of soils considered irrigable by association alone had acceptable (less than 3 %) slopes (Table 2, column 10, adjusted for slope and series). Finally, a contingency factor of 1/2 was applied to account for

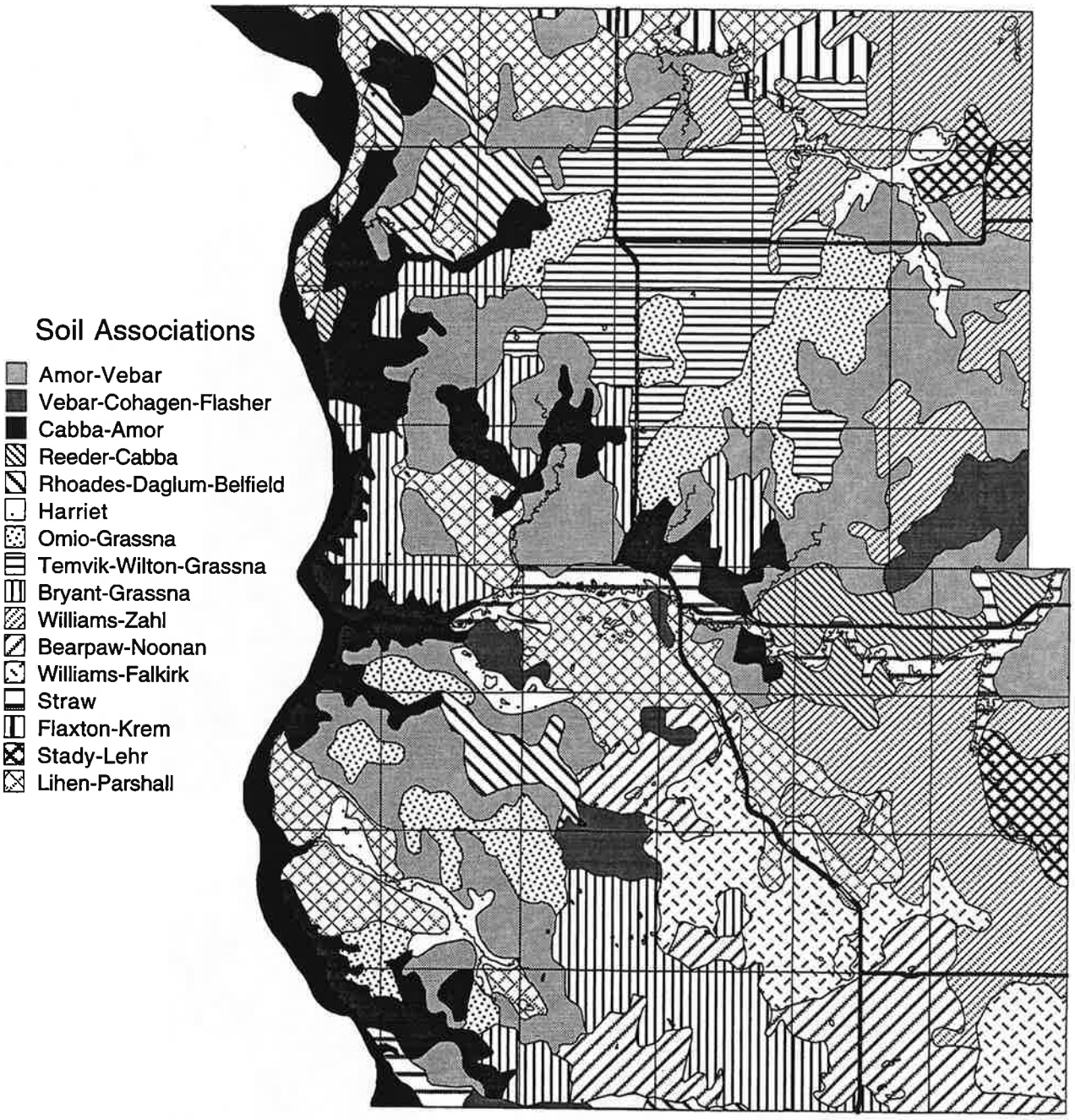

Figure Em-1. Soil association map of Emmons County ND. (From Emmons County Soil Survey, USDA-SCS 1980).

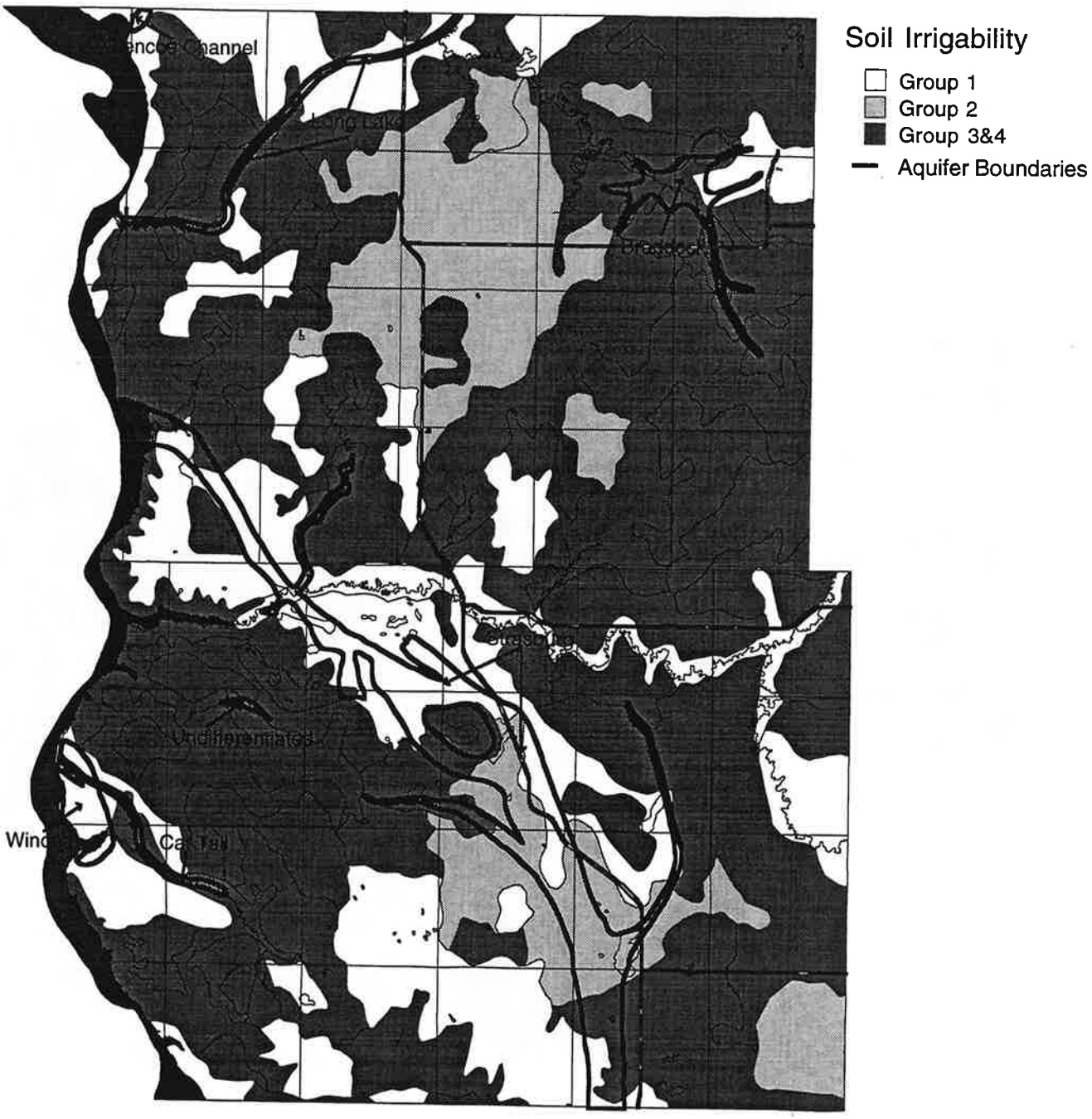

Figure Em-2. Map of boundaries of aquifers in Emmons County (From Larson, 1987).

error, interaction of soil and water suitability, and land use preference. Results in Table 2, column 11, indicated that **about 6,500 acres** (6,545 acres) **of land overlying aquifers would be considered as potentially irrigable based on soil suitability alone**.

Irrigable Land Overlying Aquifers Based on Water Supply Limitations

Supplies of water suitable for irrigation are limited in most aquifers. Estimates of water available for potential irrigation development are based on an estimated recharge of 0.3 inches per year for deep confined aquifers in glacial till, 1.2 inch per year for shallow confined aquifers, 2 inches per year for aquifers that are partly confined, and partly unconfined, and 4 inches per year for unconfined aquifers. Irrigable acreage for each aquifer is then calculated by assuming an average irrigation use of 12 inches per acre per year. The recharge coefficient is the estimated recharge divided by the 12-inch use estimate. Recharge coefficients calculated for 0.3, 1.2, 2.5, and 4 inches are 0.025, 0.1, 0.17, and 0.33, respectively. For some aquifers, gradations between values are selected, based on the known attributes of the aquifer.

Almost all of the aquifers in Emmons County are confined. However, the thickness of confining layers varies. Potential irrigated acreage was computed by multiplying the total area overlying each unconfined aquifer (Table 2, column 7) by the assigned recharge coefficient (Table 2, column 6).

A further limitation on water supply for irrigation is water quality. Probability plots for electrical conductivity (EC), sodium adsorption ratio (SAR), and boron were graphed for all water samples in the North Dakota State Water Commission data base, for each aquifer (Table 2, columns 2, 3, and 4). Estimated sustainable yield was multiplied by the most limiting fraction of suitable water based on these three chemical parameters (Table 2, column 5). Aquifers having inadequate data were either grouped with other nearby aquifers, or were adjusted using fractions obtained from probability plots for data from all aquifers in Emmons County . Results of these computations (total acreage overlying the aquifer multiplied by recharge and water quality factors) are shown on Table 2, column 8. **A total of about 7,000 acres** (7,353 acres) **was estimated as potentially irrigable using ground water, based on water supply limitations in Emmons County.**

Potential Irrigation Development from Ground Water in Emmons County

The most limiting factor in Table 2 [water limiting (column 8); or soil limiting (column 11)] is used to estimate potential irrigation development from each aquifer in Emmons County. The Braddock and Strasburg aquifers were soil limited, while the Cattail, Long Lake, and Winona aquifers were limited by long-term sustainable water supply of suitable quality. **About 6,000 acres** (6,052 acres) **are estimated as having potential for irrigation development in Emmons County.**

IRRIGATION DEVELOPMENT USING SURFACE WATER

Surface water sources in Emmons County include the Missouri river, lakes, and smaller tributaries of the Missouri River. Of these the Missouri River represents a large potential water supply. There are currently about 8,073 acres of approved water use for irrigation from the Missouri river mainstem. Smaller tributaries, have limited and ephemeral supplies of water. A total of 935 acres have been approved from tributaries of the Missouri River in Emmons County (Table 1). From 1991 through 1993 actual use was between three hundred and five hundred acres. However, because many of the non mainstem sources are ephemeral and would not be reliable sources in dry years, they are excluded from consideration for potential development. Emmons County has relatively fewer lakes than adjoining counties. Lakes are also excluded as potential water sources because of the complexities involved with lake hydrology and because of competing recreational and wildlife interests. While some lake waters would likely be available for use, they would have to be considered as individual cases. Lakes should not be considered as a potential large source of water in Emmons County.

Irrigation Development Using Water From the Missouri River

The Missouri River is by far the largest potential source of irrigation water in central North Dakota. From the standpoint of water quantity, it is treated in this study as unlimited (other factors are likely to be limiting). Access is considered to be a major limitation. Much of the land near the Missouri River is owned by the federal government. Moreover, elevations and subsequent lift for moving water to potential sites can be considerable. Irrigation is most feasible where lift from the river is least. It is also most feasible where irrigation use can begin near the river, so that financial return on the cost of conveyance facilities can be optimized. The criterion used in this study will be approximately 260 foot of maximum lift, and ability to irrigate within five miles of the river. While fluctuating levels of the Oahe Reservoir may cause some access difficulties, these are considered to be primarily engineering problems, and are relegated to later more detailed studies. Potential irrigable land using Missouri River water is summarized on Table 3.

There are two potential irrigation development tracts near the Missouri River in Emmons County. The first tract consists of a parcel of land immediately contiguous to the Missouri River on Winona Flats. The second tract, called the Horsehead Flats tract, consists of a substantial inland parcel of land accessible from the Missouri River. Locations of both tracts are shown on Figure Em-3. The deep loessial or aeolian soils of these two tracts appear to be particularly attractive for future irrigation development.

Figure Em-3. Map of tracts of land in Emmons County that may be developed for irrigation using water from the Missouri River.

Table 3. Potentially irrigable land in Emmons County, using Missouri River water .

WATER SOURCE	ECE %<1500 µS/cm	SAR %< 6	BORON %<2 mg/L	WATER USE COEFFICIENT	POTENTIAL IRRIGABLE ACRES	ADJUSTED POTENTIAL IRRIGABLE ACRES (1/2 adjusted)
Horsehead Valley Tract	100	100	100	1	**25,785**	**12,892**
Winona Flats Tract	100	100	100	1	**17,785**	**8,892**
North of Cattail Creek					7,846	3,923
South of Cattail Creek					9,939	4,970
Total					**43,570**	**21,785**

The Horsehead Flats tract is the largest, consisting of approximately 60,000 acres of potentially irrigable land. Adjusted by the contingency factor of 1/2 about **30,000 acres would be considered as land potentially available for irrigation development.** Horsehead Flats is divided into two sub tracts. The first sub tract, located north of Beaver Creek, has a northern boundary in the lower reach of Horsehead Creek. It is bounded on the west by the nearest section line from the Missouri River, on the south by the nearest section line north of Beaver Bay, and on the east a section line approximately seven miles from the Missouri River which lies at the foot of increasingly steep terrain. Approximate map locations are T 132,133 , R78,79. There appear to be no significant points prohibitive to access from the Oahe Reservoir along the reach of this tract. The second sub tract is located south of Beaver Creek, and southeast of the first sub tract. This sub tract occupies the township of T132 N and about half each of R 76 and R 77 W. The approximate eastern boundary is Highway 83, south of Linton. The Horsehead Flats tract is shown on Figure Em-3.

The second tract of potentially irrigable land is located on, and continues inland from Winona Flats, within the approximate map boundaries of T 130,131, R 79. This tract consists of two subtracts, located north and south of Cattail Creek and its inlet to the Oahe Reservoir (Figure Em-3). The western boundary of both sub tracts is the section line nearest the Oahe Reservoir, and the eastern boundary for both is approximately four miles east of the Oahe Reservoir. Total potentially irrigable land is about 18,000 acres. Adjusting by a contingency factor of 1/2 we estimate an approximate **irrigation development potential of about 9,000 acres in the Winona Flats tract.** There does not appear to be a major problem of access to the Oahe Reservoir for ether of the Winona Flats sub tracts. **Total irrigation development potential from the Missouri River is about 39,000 acres.**

Previous Estimates of Possible Development From the Missouri River

Possible irrigation development in the Horsehead Flats and Winona Units was studied extensively by the U.S. Bureau of Reclamation during the 1960s, and a feasibility report was published September of 1971. The resulting report proposed two irrigation tracts which were both less inclusive than the potential development areas indicated in this report. The U.S. Bureau of Reclamation proposal for Horsehead Flats consisted of a total of 18,200 acres (compared with a possible total development of 30,000 acres indicated for this preliminary study) located primarily in the sub tract southeast of Beaver Creek. Proposed development north of Beaver Creek was limited to canal-side parcels of land. The U.S. Bureau of Reclamation proposal for the Winona Unit, consisted of 4,600 acres compared with 9,000 acres proposed in this report. All development in the U.S. Bureau of Reclamation study was located north of Cat Tail Creek. **Total Development proposed for actual development by the U.S. Bureau of Reclamation study was about 23,000**

acres, compared with 39,000 potential acres estimated from soil suitabiltiy (and a contingency factor of 1/2) alone.

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT

Two estimates have been given for potential irrigation land development using water from the Missouri River. The first estimate is based on elevation near the Missouri River, distance from the Missouri River, and soil irrigability, consistent with methodologies laid out for this study. The second is based on an actual initial project design proposed by the U.S. Bureau of Reclamation. Estimated total potential acreage will be offered for both estimates.

There is some overlap of potential irrigation from wells and irrigation from the Missouri River. An approximate overlap of about 700 acres is estimated. Adding potential irrigation from ground water, and adjusting for this overlap, it would be estimated that a total of **about 44,500 acres would be available for potential irrigation from all sources.** Alternatively, if the U.S. Bureau of Reclamation plan is used as an upper limit on estimated irrigation, **then a total of approximately 28,500 acres would be estimated as potentially irrigable.**

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Potential Irrigation Development in Foster County, North Dakota

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT FOR FOSTER COUNTY

Two aquifers in Foster County provide most of the water for potential irrigation development. These are the Carrington and New Rockford aquifers. About 33,000 acres overlying these aquifers have soils classified as irrigable or conditionally irrigable, have slopes of less than 3 %, are free from substantial surface and subsurface drainage requirements, and lie in parcels of sufficient size for irrigation. In this study, estimates of potentially irrigable land are based on total land classified as irrigable, multiplied by a contingency factor of 1/2 to account for potential error, and land owner preferences regarding development. The contingency factor is also intended to lend a conservative bias to this report. Application of the contingency factor results in an estimate of at least 16,500 acres of irrigable land in Foster County.

Water quality for irrigation is variable. The percent of water of suitable quality for irrigation varies from as little as 60 percent to as much as 100 percent, depending on the aquifer. Estimates of long-term sustainable yield indicate that sufficient water for about 12,000 acres of irrigation is possible on a long-term basis.

Potential irrigation development is estimated by summing the most limiting resource (irrigable land or water) for each aquifer. **Results indicate that development of at least 10,500 acres for irrigation should be feasible in Foster County.** Potential for irrigation from surface water in Foster County is not substantial, and would not significantly alter this estimate. Estimates of potential irrigation development in this report compare with a total of 6,349 acres currently permitted for irrigation in Foster County. Estimated potential irrigation development is likely conservative, and it would not be implausible that some additional acres of irrigation might be developed in carefully monitored stages.

POTENTIAL IRRIGATION DEVELOPMENT IN FOSTER COUNTY NORTH DAKOTA

The purpose of this report (chapter) is to provide an evaluation of land and water available for potential irrigation development in Foster County. Methods of assessment used in this report were designed to provide a conservative estimate. These methods were described in a previous introductory section. It is emphasized that the findings of this report are based on general information. They are preliminary, and they should not be used for individual project planning without further local in-depth analysis. For the sake of continuity in computation, data on computation tables are provided to the nearest digit. However, this should not lead to the conclusion that this report can estimate acreage with such a high level of precision. **In the text of this report, the final summary estimates resulting from table computations are rounded to the nearest 500 acres.** These final rounded numbers reflect more appropriately the general character of these estimates.

In Foster County there are currently 21 irrigation permits for a total of 6,349 acres. Actual water use varies. Between 1991 and 1993 the largest irrigated acreage was 3,094 in 1992. Least irrigation (1,883 acres) occurred in 1993, which was an extremely wet year.

IRRIGATION DEVELOPMENT FROM GROUND WATER

Assessment of potential irrigable land in this report will not be limited to or based on actual current water permits, or on current actual irrigated acreage. Rather it will be based on evaluation of the water and soil resource. In Foster County nine principal aquifers have been identified as potential sources for irrigation. These are listed on Table 1. There are two possible limiting factors affecting potential irrigation development using ground water. These are (1) irrigable land within practical distance of the water source , and (2) available water of suitable quality in close proximity to irrigable land.

Total Irrigable Soils

There are approximately 411,240 acres in Foster County. According to a study conducted by North Dakota State University (NDSU) there are about 335,368 acres of irrigable and conditionally irrigable land in Foster County (Omodt, written communication, 1982). Of this most, or about 89 %, is classified as conditionally irrigable because of slope, drainage requirements, or slowness of internal drainage.

Table 1. Resources for potential irrigation development in Foster County, ND. EC is the electrical conductivity of water; SAR is the sodium adsorption ratio of water; and Boron is the concentration of boron in water. Potential irrigable acres based on water limitations (column 8) are calculated by multiplying the total acreage (column 7) by the recharge coefficient coefficient in column (6) as described in the text, and by adjusting for water quality (column 5). Land mapped in irrigable soils series, and having a slope of less than 3% (column 10) is calculated from land area mapped in irrigable associations overlying the aquifer (column 9), adjusted for the proportion of the association attributed to soils of irrigation suitable series, and by an adjustment factor (0.63) accounting for slopes greater than 3%. The final estimate of potential irrigation development is half of column 10. **Bold type** indicates most limiting estimate of potential irrigation, used in final estimates of potential irrigation dev elopment. (c) is shallow confined, (c†) is deep confined, (c/u) is variably confined and unconfined, and (u) is unconfined.

(1) WATER SOURCE	(2) ECE %<1500 µS/cm	(3) SAR %< 6	(4) BORON %<2 mg/L	(5) WATER QUALITY COEFFICIENT	(6) RECHARGE COEFFICIENT	(7) AREA OVERLYING AQUIFER acres	(8) POTENTIAL IRRIGABLE ACRES-WATER LIMIT acres	(9) LAND MAPPED IN IRRIGABLE ASSOCIATIONS acres	(10) LAND MAPPED IN IRRIGABLE SOIL SERIES, SLOPE < 3% acres	(11) POTENTIAL IRRIGABLE SOIL OVERLYING AQUIFER acres
Bald Hill Creek -c	-	-	-	0.06**	0.1	2,707	**162**	2,707	1,108	554
Carrington / Rosefield -c/u	95	97	97	0.97	0.17	36,448	**6,196**	34,528	12,398	6,199
Eastman -c†	80	60	100	0.6	0.05	11,276	**338**	11,276	1,775	887
James River c/u	-	-	-	0.6**	0.17	4,960	**506**	4,480	2,116	1,058
Johnson Lake -c	-	-	- *	0.6**	0.1	371	22	160	50	25
Juanita Lake -u	100*	100*	100	1*	0.33	3,993	1,318	3,993	1508	**754**
New Rockford -c†	75	75	100	0.75	0.05	38,617	**1,448**	31,257	11,617	5,808
Pipestem Creek -u	80*	100*	100*	1	0.33	6,208	2,049	6,208	1,954	**977**
Russel Lake -c	-	-	-	0.6**	0.21	1,465	**185**	1,145	576	288
Total						106,045	12,224	95,754	33,102	16,550

* Sparse data.
** Insufficient data. Water quality coefficient based on other nearby aquifers.

The classification used in this report is a much more restrictive subset of that used in the NDSU study. A soil association map (USDA-SCS, unpublished) is provided on Figure Fo-1. All soils requiring extensive surface or internal drainage are excluded from consideration, and all soils having slopes of more than 3 % are also excluded. Using the criteria of this study, about 58,440 acres are classified as Group 1 (irrigable without limitations, slope less than 3 %) soils based on Foster County SCS soil survey tabulations. There are an additional 17,470 irrigable acres in the Group 2 category (irrigable with limitations). Thus, based on soil suitability alone, there are about 75,910 acres of potentially irrigable land.

All federal, state, and municipal land is excluded from the potentially irrigable acres. There are about 4,748 acres of state and federal land, and about 4,480 acres of municipal land, for a total of about 9,228 acres of government land. About 18 % of all land in Foster County is classified as irrigable according to standards of this study. Applying this proportion to government land gives 1,703 acres of excluded land that might be considered irrigable. After subtracting estimated irrigable government land, approximately **74,000 acres** (74,216 acres) **would be considered to be potentially irrigable based on soil factors alone.** A map of soil Groups (irrigable, conditionally irrigable, and non irrigable) as defined for this study is provided on Figure Fo-2. There is one soil association **(Fram-Heimdal-Emrick)** for which about 32 % of the land is in Group 1 (irrigable without condition), but almost half of the land requires drainage (Group 3). On the irrigability map (Figure Fo-2) this soil is classified as Group 3&4 (non irrigable). However, the reader should be aware that there is substantial irrigable soil included in this soil association. A large portion of northeastern Foster County, including much of the northern portion of the Carrington aquifer and the Rosefield aquifer is mapped in this soil association. The area mapped as Fram-Heimdal-Emrick soil is shown on Figure Fo-1.

Estimates of Irrigable Soil Overlying Aquifers

The overall estimates of irrigable soils discussed above were taken from soil survey summary tables and were adjusted for slopes greater than 3%. Estimates of irrigation-suitable soil overlying aquifers were calculated by integrating the areas of mapped soil associations within mapped aquifer boundaries. Area mapped to soil associations considered to be predominantly irrigable were adjusted by the percent of land individual soil series classified as irrigable within the association. In addition, irrigable series were adjusted to account for slopes greater than 3% using a factor of 0.63. Foster County soil summary table data indicated that about 63 % of soils mapped in series considered irrigable, had slopes of less than 3 %. Finally, a 1/2 contingency factor was applied to all estimates of irrigable soil area. Results in Table 1, column 11, indicates that **about 16,500 acres** (16,550 acres) **of land overlying aquifers would be considered as potentially irrigable based on soil suitability alone**. Most of this land overlies the Carrington and New Rockford aquifers.

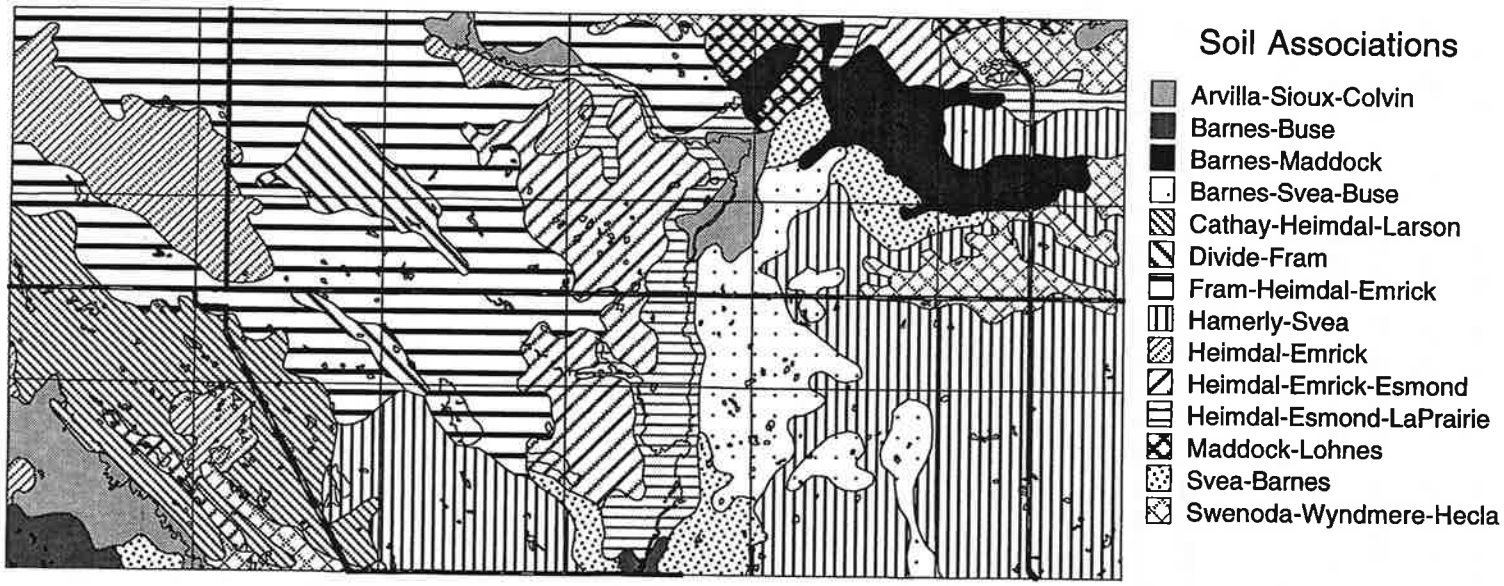

Figure Fo-1. Soil association map of Foster County ND. (From Foster County Soil Survey, USDA-SCS , Unpublished 1995).

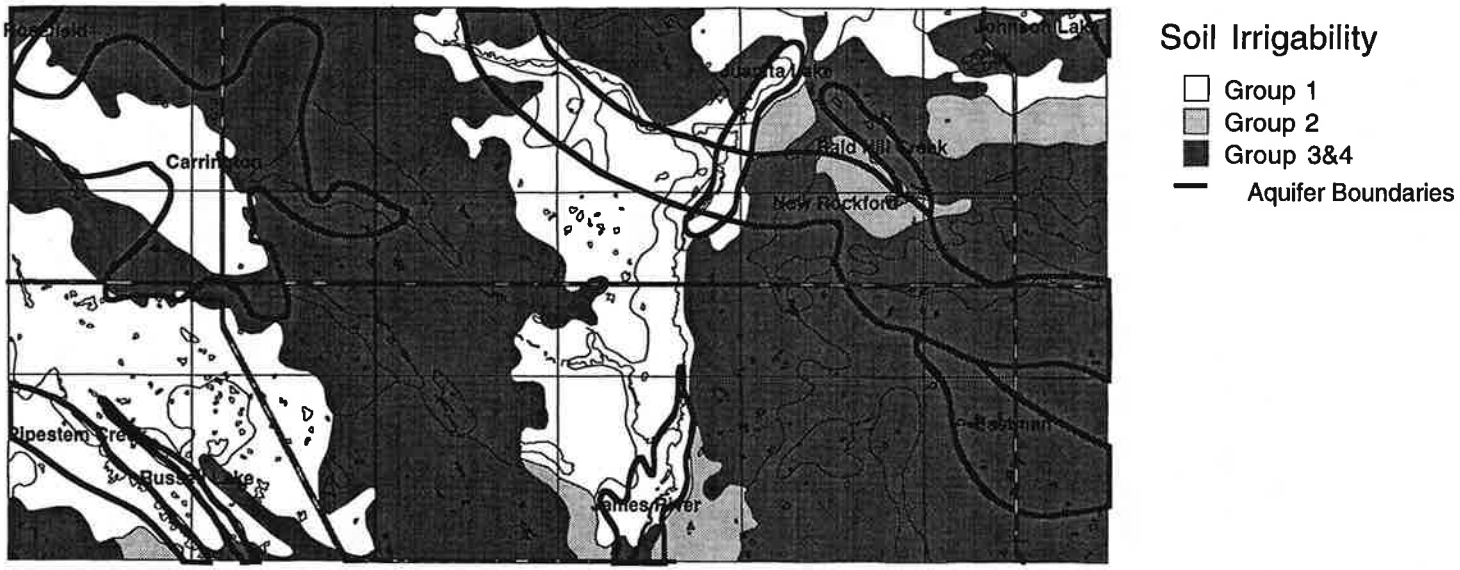

Figure Fo-2. Map of boundaries of the principal aquifers in Foster County, ND. (From Trapp, 1968).

Potential Irrigation Development Over Aquifers Based on Water Supply Limitations

Ground-water resources in Foster County have variable quality for irrigation use. Between 70 and 100 % of the ground water from aquifers considered on Table 1 are of suitable quality for irrigation. Water quality is evaluated on the basis of suitable electrical conductivity (ECE), sodium adsorption ratio (SAR), and Boron concentration (Table 1). Estimates of water available for potential irrigation are based on an estimated recharge of 0.3 inches per year for deeper confined aquifers in glacial till, 1.2 inch per year for shallow confined aquifers, 2.5 inches per year for aquifers that are partly confined, and partly unconfined, and 4 inches per year for unconfined aquifers. Irrigable acreage for each aquifer is then calculated by assuming an average of 12 inches per acre per year irrigation. The recharge coefficient is the estimated recharge divided by the 12-inch use estimate. Recharge coefficients calculated for 0.3, 1.2, 2.5, and 4 inches are 0.025, 0.1, 0.21, and 0.33, respectively. In some cases, depending on the aquifer, ranges of values between these coefficients are selected.

Irrigation acreage based on sustainable water use is further adjusted by the water quality coefficient, which is the probability of obtaining water suitable for irrigation in a given well (Table 1, column 5). The most limiting parameter (of ECE, SAR, Boron) is used to adjust for water quality. The resulting irrigable acreage estimate based on recharge and water quality is in Table 1, column (8). **About 12,000 acres** (12,224 acres) **are estimated as potentially irrigable, based on estimates of available water of suitable quality for irrigation.**

Potential Irrigation Development from Ground Water in Foster County

The most limiting factor in Table 1 [water limiting (column 8); or soil limiting (column 11)] is used to estimate potential irrigation development from ground water in Foster County. Parcels of land less than 130 acres are not included in the sum of potentially irrigable acres. Irrigation development from the Pipestem Creek and Juanita Lake aquifers is limited by available soil. Development from all other aquifers is limited by estimated sustainable yield. However, in most cases soil and water resources are fairly closely matched. **The sum of potentially irrigable acres based on the most limiting resource is about 10,500 acres** (10,566 acres). If the 1/2 contingency factor were not applied to available soil, the total would be closer to 12,000 acres. This compares with about 6,117 acres already permitted for irrigation using ground water in Foster County. Actual water use for irrigation between 1991 and 1993 varied from as little as 1,633 acres irrigated in 1993 to 2,864 acres irrigated in 1992.

Additional Comments

It is considered that the estimate of 10,500 to 12,000 acres of irrigation development is conservative, and that some additional development might be possible. Estimates were based on computations of sustained yield. Some additional development might be allowable on the basis of limited mining from large aquifers, and might be sustainable for many years without excessively depleting the aquifers. As many as 2,000 additional acres might be irrigable from limited mining. This, however, would have to be considered on a case by case basis, and should not be considered as a reliable estimate of available water.

The State Water Commission managing hydrologist for Foster County (Alan Wanek, personal communication, May 1995) has noted that the actual boundaries of the Carrington aquifer are more constricted than shown on the digitized copy of the Foster County Study map (Figure 2). However, the change in boundaries conforming to more recent information corresponds well with the boundaries of the irrigable soil on Figure 2. Thus, more limited area of the Carrington aquifer conforming to more recent boundaries would not affect the final estimate of potentially irrigable land based on most limiting factors. Only non irrigable soil would be eliminated by the changed boundary.

IRRIGATION USING SURFACE WATER

There are currently 232 acres approved for irrigation using surface water in Foster County. Of this, annual use is usually about 250 acres. Minimum recorded use was 230 acres in 1992. While the upper reaches of Pipestem Creek and the James River flow through Foster County, these waters are already heavily appropriated, and further irrigation use is unlikely. There are numerous small lakes, potholes, and sloughs in Foster County. However, these are excluded as potential water sources because of the complexities involved with lake hydrology and because of competing recreational and wildlife interests. While some lake waters would likely be available for use, they would have to be considered as individual cases. Total current irrigation from surface water is insubstantial, and does not significantly effect the overall total of potential development.

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT

Approximately 10,500 acres of potential irrigation, all from ground water, appears to be available for development in Foster County. Additional development

might be feasible under appropriate conditions, but would likely have to be implemented in carefully monitored stages.

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Potential Irrigation Development in Grant and Morton Counties, North Dakota

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT FOR GRANT AND MORTON COUNTIES

There are five aquifers in Grant County, and seven aquifers in Morton County which may provide water for potential irrigation development. In Grant County, about 9,000 acres overlying aquifers have soils classified as irrigable or conditionally irrigable, have slopes of less than 3 %, are free from substantial surface and subsurface drainage requirements, and lie in parcels of sufficient size for irrigation. In this study, estimates of potentially irrigable land are based on total land meeting the above criteria, multiplied by a contingency factor of 1/2 to account for potential error, and land owner preferences with regard to irrigation development. The contingency factor is also intended to lend a conservative bias to this report. Application of the contingency factor results in an estimate of at least 4,500 acres of irrigable land overlying aquifers in Grant County. In Morton County, about 27,000 acres overlying aquifers have soils meeting the criteria described above. Application of the 1/2 contingency factor results in an estimate of at least 13,500 acres of irrigable land overlying aquifers in Morton County.

Water quality for irrigation is variable between aquifers in both Grant and Morton Counties. Between 17 and 45 % of ground water sampled is of suitable quality for irrigation in Grant County, based on the criteria of this study. Estimates of long-term sustainable yield indicate that sufficient water for about 3,500 acres of irrigation is possible on a long-term basis. After considering both land and water limitations, it is estimated that about 2,000 acres would be potentially available for irrigation development using ground water in Grant County. In Morton County, about 45% of ground water sampled is of suitable quality for irrigation. Estimates of long-term sustainable yield indicate that sufficient water for about 10,500 acres of irrigation is possible on a long-term basis. After considering both land and water limitations, it is estimated that about 9,000 acres would be potentially available for irrigation development in Morton County.

Potential substantial sources of surface water for irrigation in Grant and Morton Counties include the Missouri River, the Cannonball River, and the Heart River and Lake Tschida. A total of at least 13,500 acres of irrigation have been permitted for irrigation under U.S. Bureau of Reclamation Water Permit No. 250B, using waters released from the Heart Butte Dam. Of this about 7,000 acres are currently under irrigation. An additional 6,500 acres may be irrigated. As many as 7,500 acres may be developed for irrigation in Morton County using water from the Missouri River. About 4,500 acres of this total are already under irrigation. A total of up to 2,000 acres of irrigation may be possible using other sources, including the Cannonball River. Most of this total is already permitted and under irrigation. Total estimated potential irrigation for Grant and Morton Counties combined using all available surface-water sources would be about 23,000 acres.

Considering all potential ground-water and surface-water sources, there is sufficient water and irrigable soil to allow for development of 28,000 to 31,000 acres of irrigation in Grant and Morton Counties combined.

POTENTIAL IRRIGATION DEVELOPMENT IN GRANT AND MORTON COUNTIES, NORTH DAKOTA

The purpose of this report (chapter) is to provide an evaluation of land and water available for potential irrigation development in Grant and Morton Counties. Methods of assessment used in this report were designed to provide a conservative estimate. These methods were described in a previous introductory section. It is emphasized that the findings of this report are based on general information. They are preliminary in nature, and they should not be used for individual project planning without further local in-depth analysis. For the sake of continuity in computation, data on computation tables are provided to the nearest digit. However, this should not lead to the conclusion that this report can estimate acreage with such a high level of precision. **In the text of this report, the final summary estimates resulting from table computations are rounded to the nearest 500 acres.** These final rounded numbers reflect more appropriately the general character of these estimates.

CURRENT IRRIGATION DEVELOPMENT IN GRANT AND MORTON COUNTIES

In Grant County there is currently no approved irrigation from Ground Water. From surface-water sources 2,051 acres are approved for irrigation from the Cannonball River and its tributaries. The distribution of permits is shown on Table 1. Although 429 acres are approved for irrigation from the Cannonball River, actual use did not exceed 179 acres from 1991 to 1993. Also, of 1,622 acres approved for irrigation from tributaries of the Cannonball River, actual use from 1991 through 1993 varied from as little as 454 to as much as 904 acres.

In Morton County there are currently 1,022 acres of land permitted for irrigation using ground water. Permits for irrigation use of surface water total 5,473 acres, of which all but 1,474 acres are irrigated using Missouri River water (Table 1).

One major source of water currently permitted, but not fully developed, is that supplied by releases from the Heart Butte Dam under U.S. Bureau of Reclamation (USBR) Water Permit 250 B (WP 250 B). WP 250 B allows for the irrigation of 13,538 acres in Grant and Morton Counties combined. Current development and use is between 7,000 and 7,500 acres (Table 1). Although the sole point of diversion for irrigation is in Grant County, actual use is about 48% for Grant County and 52% for Morton County (Table 1). An additional 6,000 to 6,500 acres of irrigation can be developed in Grant and Morton Counties under the current water permit allocation.

Table 1. Summary of current water permit allocations, and current water use in Grant and Morton Counties, ND. Bold type rows are totals. Normal type rows are subtotals. * Indicates that this sum is a total for both Grant and Morton Counties. ** Indicates that these figures approximate, based on a 48% Grant County and 52% Morton County current water use allocation from USBR Water Permit No. 250 B.

WATER SOURCE	County	PERMITED LAND (ACRES)	IRRIGATED ACRES IN 1991	IRRIGATED ACRES IN 1992	IRRIGATED ACRES IN 1993
Ground Water	**Grant**	**0**	**0**	**0**	**0**
	Morton	**1,022**	**473**	**484**	**405**
Surface Water	**Grant**	**2,059**			
Cannonball River (CR)	Grant	429	179	178f	148
CR Tributaries	Grant	1,622	454	524	904
	Morton	**5,473**			
Missouri River	Morton	3,999	2,190	2,548	685
Heart River	Morton	462	54	82	202
Cannonball River	Morton	398	0	0	0
Tributaries	Morton	614	310	313	162
USBR Water Permit No. 250 B Heart River	USBR Approved Release Allocation From Lake Tschida / Total	**13,538***	**7,055**	**7,400**	**7,308**
	Grant **		3,386**	3,552**	3,508**
	Morton**		3,668**	3,848**	3,800**

TOTAL LAND AVAILABLE FOR IRRIGATION IN GRANT AND MORTON COUNTIES

In Grant County there are a total of 1,061,120 acres, of which an estimated 203,085 acres are irrigable without limitation, and of which approximately 23,800 acres are conditionally irrigable. This estimate is based on a survey of soils by series provided by the Grant County Soil Survey (USDA-SCS, 1988). Soils requiring drainage are not included in the conditionally irrigable class in this study. Also, soils having slopes of more than 3% are excluded. About 18% of the soils classified as irrigable in Grant County have slopes greater than 3%. Of soils classified as conditionally irrigable, the main limiting condition is fineness of soil. Thus, about 226,885 acres, or about 21 % of the soils in the county are considered to be irrigable. This compares with an estimated total of 342,295 (about 31%) irrigable and conditionally irrigable acres as estimated by an North Dakota State University (NDSU) report (Omodt, written communication,1982). However, the NDSU study includes undulating soils and wet soils requiring drainage, that are not included in this study. In Grant County there are 37,409 acres of state and federal park and refuge land, and about 6,400 acres in town lands. Total excluded land is about 43,809 acres. Of the excluded land, 21% (about 9,200 acres) is estimated to be irrigable or conditionally irrigable. This amount is subtracted from the total estimate of irrigable land. About 217,685 acres are estimated to be irrigable on the basis of soil alone in Grant County.

In Morton County there are a total of 1,246,500 acres. The soil survey table of soil series for Morton County is not yet available. However a previous study by NDSU (Omodt, written communication, 1982) has indicated that a total of 129,615 acres would be classed as either irrigable or conditionally irrigable. The NDSU irrigability classification is somewhat less restrictive than that used in this analysis. It includes soils of slightly higher slope, and also soils that would be irrigable with surface or internal drainage, while this study has excluded these soils. Depending on which soils predominate in the county, the NDSU survey varies from estimates of irrigable land used in this study. For example, in Oliver County, estimates of irrigable acreage in the NDSU study are identical to those used in this report, while in Mercer County the NDSU estimate is double that used in this report. This is not due to inaccuracy of either classification, but rather to additional restrictions placed on the classification used in this study. According to the NDSU report, 83,615 acres of soils are classified as irrigable, and 46,000 acres of soil classified as conditionally irrigable are mapped in Morton County. Approximately 12,160 acres are occupied by cities and towns, and federal and state park and refuge land comprise about 20,759 acres. This estimate is adjusted by the percent of irrigable land (10%) to estimate excluded irrigable land. Subtracting the result (2,075 acres) gives a final estimate of 127,540 acres of soil potentially available for irrigation development on the basis of soil alone in Morton County.

POTENTIAL IRRIGATION DEVELOPMENT FROM GROUND WATER IN GRANT COUNTY

Estimates of Irrigable Soil Overlying Aquifers

The estimates of irrigable soils discussed above were taken from soil survey summary tables and were adjusted for slopes greater than 3%. Estimates of irrigation-suitable soil overlying aquifers were calculated by integrating the areas of mapped soil associations within mapped aquifer boundaries (Table 2, column 9). A map of soil associations in Grant County is shown on Figure Gr/Mo-1. A map of irrigable soil associations is shown on Figure Gr/Mo-2. Areas mapped to soil associations considered to be predominantly irrigable were adjusted by the percent of soil series within the association considered to be irrigable. In addition, irrigable series were adjusted to account for slopes greater than 3% using a factor of 0.82 (Table 2, column 10). Finally, a 1/2 contingency factor was applied to all estimates of irrigable soil area. Results in Table 2, column 11 indicated that in Grant County **about 4,500** (4,425) **acres of land overlying aquifers would be considered as potentially irrigable based on soil suitability alone.**

Irrigable Land Overlying Aquifers Based on Water Supply Limitations

Supplies of water suitable for irrigation are limited in most aquifers. Estimates of water available for potential irrigation development are based on an estimated recharge 0.3 inches per year for deeper confined aquifers in glacial till, 1.2 inch per year for shallow confined aquifers, 2 inches per year for aquifers that are partly confined, and partly unconfined, and 3 inches per year for unconfined aquifers. Irrigable acreage for each aquifer is then calculated by assuming an average of 12 inches per acre per year irrigation. The recharge coefficient is the estimated recharge divided by the 12-inch use estimate. Recharge coefficients calculated for 0.3, 1.2, 2.5, and 4 inches are 0.025, 0.1, 0.17, and 0.25, respectively. Slightly lower recharge estimates and sustained yield coefficients are used for Grant County, than for counties farther east because of somewhat lower (about 2 inches per year) average annual precipitation. In Grant County all of the shallow aquifers are variably confined and unconfined. All of the recharge coefficients on Table 2 are therefore 0.17.

Irrigation acreage based on sustainable water use is further adjusted by the water quality coefficient, which is the probability of obtaining water suitable for irrigation in a given well (Table 2, column 5). The most limiting parameter is used to adjust for water quality. The resulting irrigable acreage estimate based on recharge and water quality is in Table 2, column (8). **About 3,500** (3,475) **acres are estimated as potentially irrigable, based on estimates of available water of suitable quality for irrigation.**

Table 2. Resources for potential irrigation development in Grant County, ND. EC is the electrical conductivity of water; SAR is the sodium adsorption ratio of water; and Boron is the concentration of boron in water. Potential irrigable acres based on water limitations (column 8) are calculated by multiplying the total acreage (column 7) by the recharge coefficient coefficient in column (6) as described in the text, and by adjusting for water quality (column 5). Land mapped in irrigable soils series, and having a slope of less than 3% (column 10) is calculated from land area mapped in irrigable associations overlying the aquifer (column 9), adjusted for the proportion of the association attributed to soils of irrigation suitable series, and by an adjustment factor (0.82) accounting for slopes greater than 3%. The final estimate of potential irrigation development is half of column 10. **Bold type** indicates most limiting estimate of potential irrigation, used in final estimates of potential irrigation dev elopment. (c) indicates that aquifer is confined, (u) indicates unconfined, (c/u) indicates variably confined and unconfined.

(1) WATER SOURCE	(2) ECE %<1500 µS/cm	(3) SAR %< 6	(4) BORON %<2 mg/L	(5) WATER QUALITY COEFFICIENT	(6) RECHARGE COEFFICIENT	(7) AREA OVERLYING AQUIFER acres	(8) POTENTIAL IRRIGABLE ACRES-WATER LIMIT acres	(9) LAND MAPPED IN IRRIGABLE ASSOCIATIONS acres	(10) LAND MAPPED IN IRRIGABLE SOIL SERIES, SLOPE < 3% acres	(11) POTENTIAL IRRIGABLE SOIL OVERLYING AQUIFER acres
Cannonball River Valley -c/u	-	-	-	0.21	.17	20,696	**724**	6,560	2,958	1,479
Cedar Creek -c/u	-	-	-	0.45	.17	14,124	1,080	2,080	1,193	**597**
Elm Creek -c/u	55	45	69	0.45	.17	5,710	**120**	2,880	1,417	708
Heart River -c/u	-	-	-	0.45	.17	11,422	**874**	6,160	3,283	1,641
Shields -c/u	45	45	95	0.45	.17	8,844	677	1,280	0	**0**
Total						60,796	**3,475**	18,960	8,851	4,425

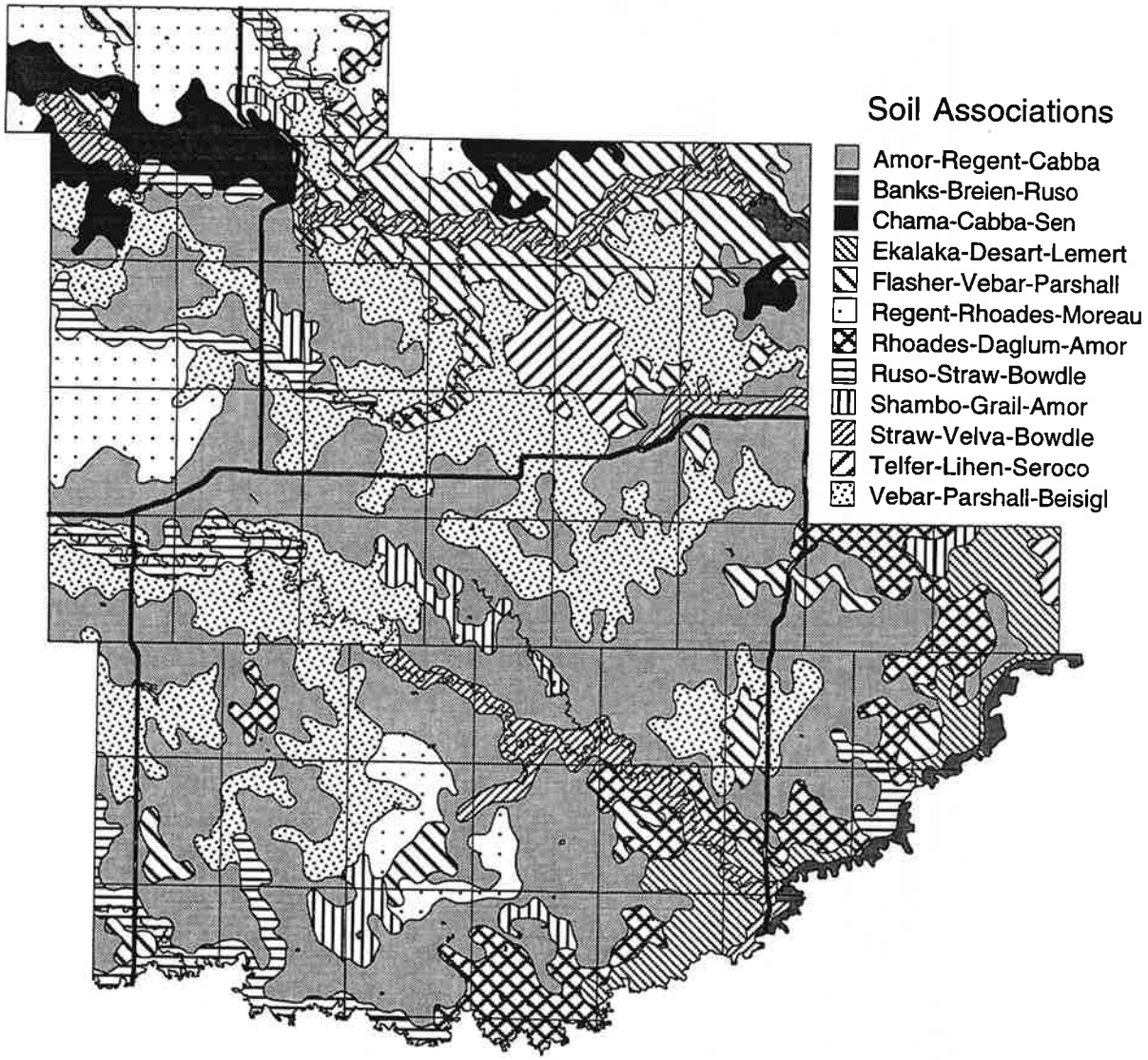

Figure Gr/Mo-1. Soil association map of Grant County ND. (From Grant County Soil Survey, USDA-SCS 1988).

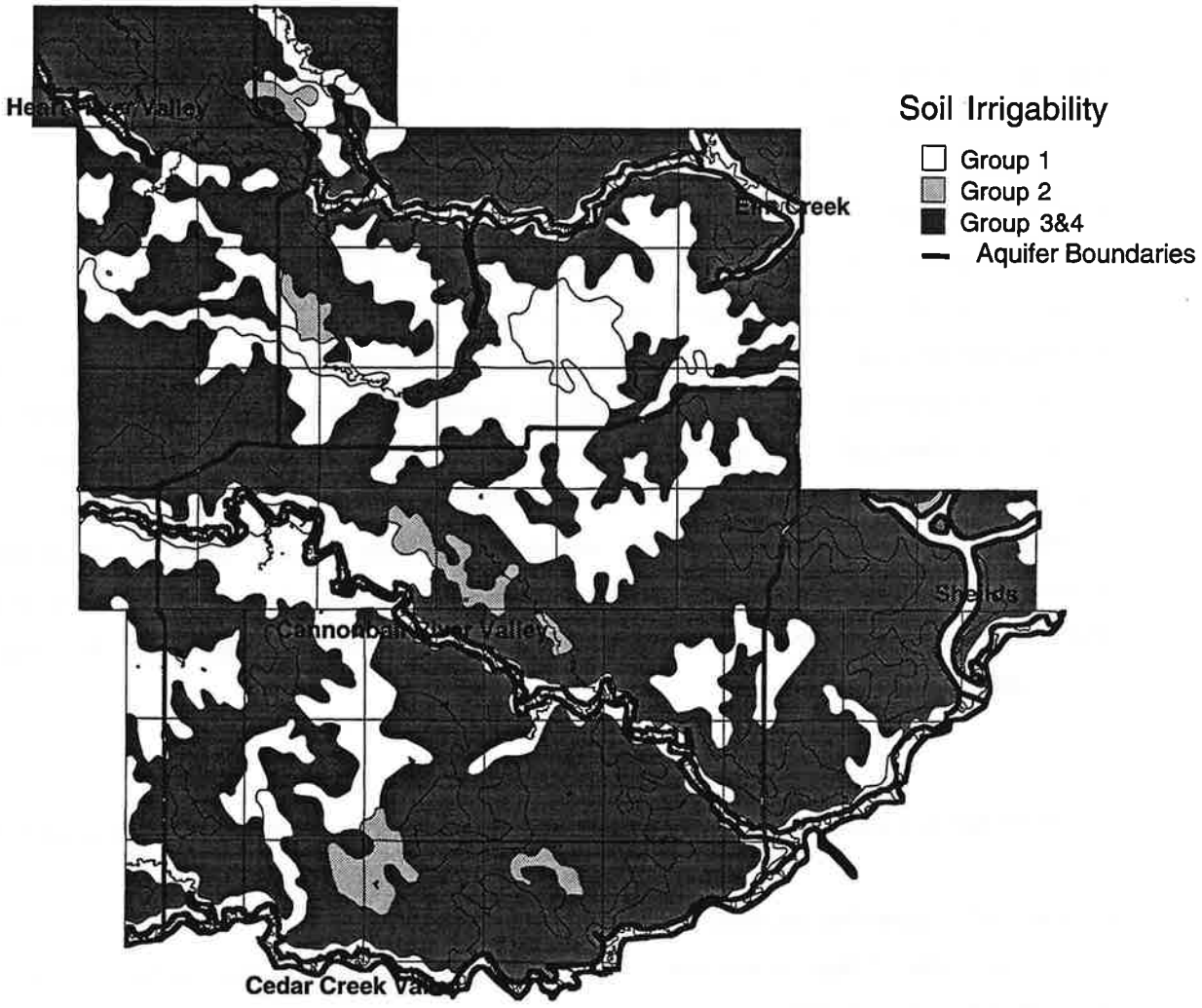

Figure Gr/Mo-2. Map of boundaries of aquifers in Grant County (From Randich,1979).

Potential Irrigation Development from Ground Water in Grant County

The most limiting factor in Table 2 [water limiting (column 6); or soil limiting (column 9)] is used to estimate potential irrigation development from ground water in Grant County. Water is most limiting for the Cannonball River, Elm Creek, and Heart River Aquifers, while soil is most limiting for the Cedar Creek and Shields aquifers. Based on Table 2, **about 2,000** (2,315) **acres are estimated as having potential for irrigation development from ground water in Grant County.** This compares with no current development of irrigation from ground-water.

Additional Comments

All of the aquifers considered for potential development have very low probabilities (17 to 45 percent chance) of obtaining good quality water for irrigation from a given well. Although development from such supplies is possible, there are additional problems of finding water of suitable quality which add to the expense and difficulty of development. In addition, the Heart River, Cedar Creek, and Cannonball Valley aquifers often have likely pumping rates of less than 50 gpm. Such a slow rate of pumping would necessitate the manifolding of wells, and further complicate the process of development. Thus, **while irrigation development from ground water in Grant County is possible, it will likely be a slow, case by case process of expansion. The ground-water supplies in Grant County are not likely situated for large-scale development in a short period of time.**

POTENTIAL IRRIGATION DEVELOPMENT FROM GROUND WATER IN MORTON COUNTY

Estimates of Irrigable Soil Overlying Aquifers

Estimates of irrigation-suitable soil overlying aquifers were calculated by integrating the areas of mapped soil associations within mapped aquifer boundaries (Table 3, column 9). A map of soil associations in Morton County is shown on Figure Gr/Mo-3. A map of irrigable soil associations is shown on Figure Gr/Mo-4. Area mapped to soil associations considered to be predominantly irrigable were adjusted by the percent of soil series within the association considered to be irrigable. Soil series acreage summaries have not yet been published for Morton County. The overall estimate of irrigable soils by series provided by NDSU (Omodt, written communication, 1982) does not conform to the 3% slope maximum or the non drainage requirement of this study. For this reason, a slope adjustment factor of 0.5 is used, based on common values for other counties (Table 3, column

Table 3. Resources for potential irrigation development in Morton County, ND. EC is the electrical conductivity of water; SAR is the sodium adsorption ratio of water; and Boron is the concentration of boron in water. Potential irrigable acres based on water limitations (column 8) are calculated by multiplying the total acreage (column 7) by the recharge coefficient coefficient in column (6) as described in the text, and by adjusting for water quality (column 5). Land mapped in irrigable soils series, and having a slope of less than 3% (column 10) is calculated from land area mapped in irrigable associations overlying the aquifer (column 9), adjusted for the proportion of the association attributed to soils of irrigation suitable series, and by an adjustment factor (0.50) accounting for slopes greater than 3%. The final estimate of potential irrigation development is half of column 10. **Bold type** indicates most limiting estimate of potential irrigation, used in final estimates of potential irrigation dev elopment. (c) indicates that aquifer is confined, (u) indicates unconfined, (c/u) indicates variably confined and unconfined.

(1) WATER SOURCE	(2) ECE %<1500 µS/cm	(3) SAR %< 6	(4) BORON %<2 mg/L	(5) WATER QUALITY COEFFICIENT	(6) RECHARGE COEFFICIENT	(7) AREA OVERLYING AQUIFER acres	(8) POTENTIAL IRRIGABLE ACRES-WATER LIMIT acres	(9) LAND MAPPED IN IRRIGABLE ASSOCIATIONS acres	(10) LAND MAPPED IN IRRIGABLE SOIL SERIES, SLOPE < 3% acres	(11) POTENTIAL IRRIGABLE SOIL OVERLYING AQUIFER acres
Elm Creek -c/u	55	45	69	.45	0.17	46,585	**3,564**	37,982	9,496	4,748
Heart River -c/u	-	-	-	.45*	0.17	17,203	**1,316**	16,883	6,753	3,377
Killdeer -c/u	30	50	99	.33	0.17	12,236	936	960	0	**0**
Little Heart -c/u	-	-	-	.45*	0.17	42,796	3,274	21,848	6,336	**3,168**
Saint James -c/u	-	-	-	.45*	0.17	7,232	**553**	4,160	1,102	1,085
Shields -c/u	45	45	95	.45	0.17	5,446	417	973	311	**155**
Sims -c/u	-	-	-	.45*	0.17	2,794	214	800	52	**26**
Square Butte -c/u	-	-	-	.45*	0.17	5,747	**440**	5,427	2,171	1,085
Total						140,039	10,713	89,033	26,221	13,644

* No water quality data were available. Used 0.45 coefficient.

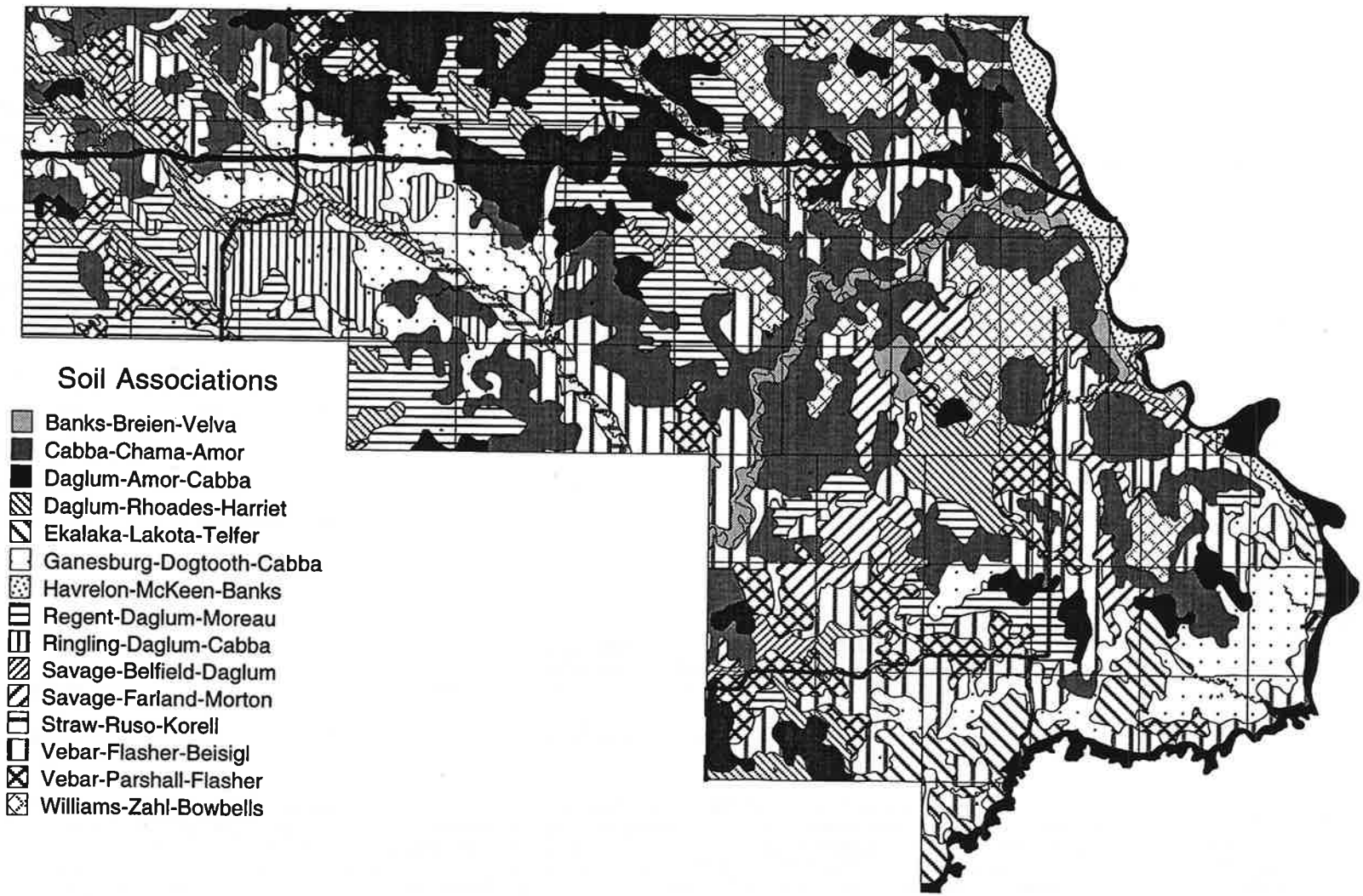

Figure Gr/Mo-3. Soil association map of Morton County ND. (From Morton County Soil Survey, USDA-SCS, unpublished 1995).

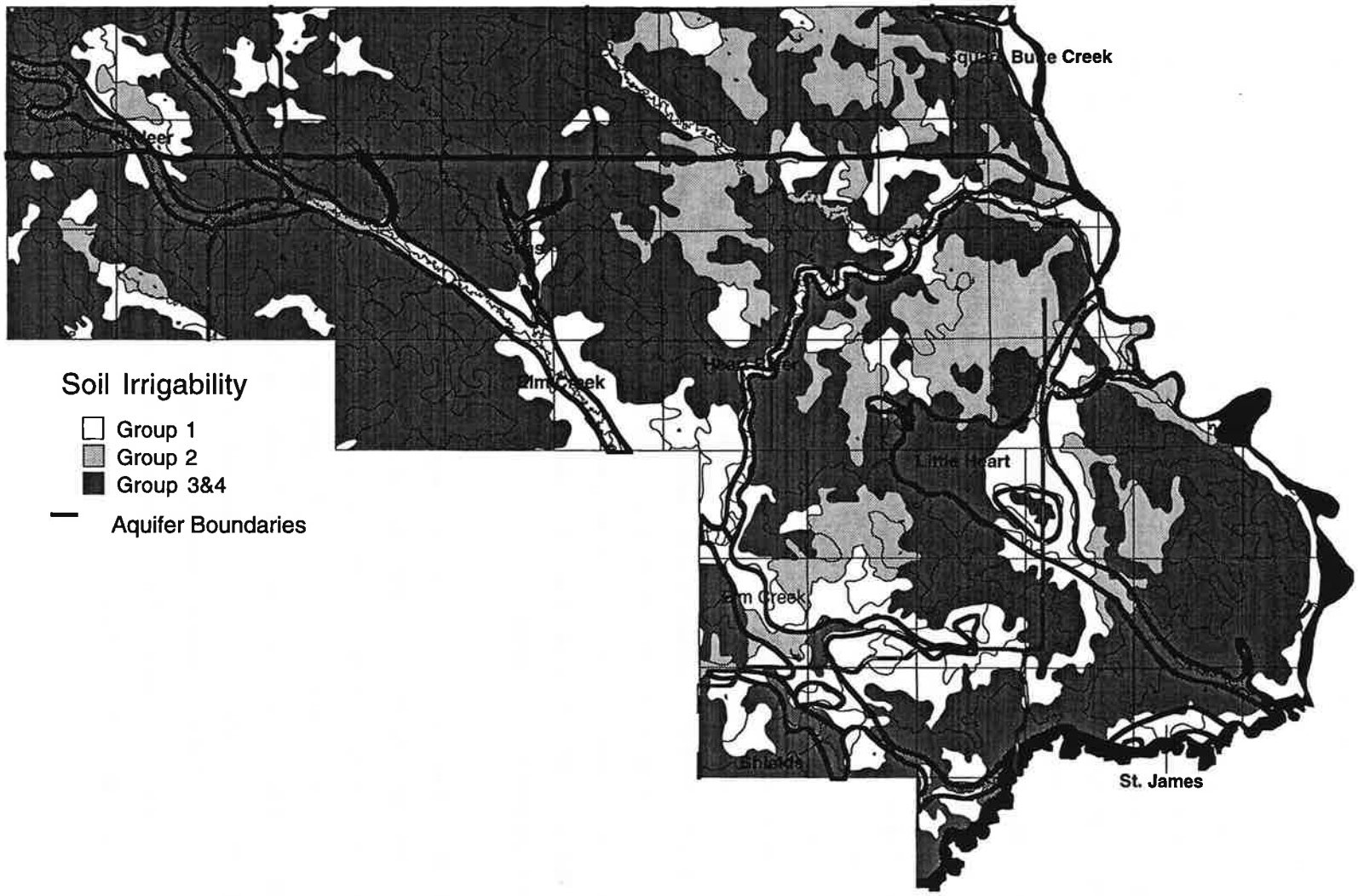

Figure Gr/Mo-4. Map of boundaries of aquifers in Morton County (From Ackerman, 1980).

10). Finally, a 1/2 contingency factor was applied to all estimates of irrigable soil area. Results in Table 3, column 11 indicated that in Morton County **about 13,500** (13,644) **acres of land overlying aquifers would be considered as potentially irrigable based on soil suitability alone.**

Irrigable Land Overlying Aquifers Based on Water Supply Limitations

Supplies of water suitable for irrigation are limited in most aquifers. Estimates of water available for potential irrigation development are based on an estimated recharge 0.3 inches per year for deeper confined aquifers in glacial till, 1.2 inch per year for shallow confined aquifers, 2 inches per year for aquifers that are partly confined, and partly unconfined, and 3 inches per year for unconfined aquifers. Irrigable acreage for each aquifer is then calculated by assuming an average of 12 inches per acre per year irrigation. The recharge coefficient is the estimated recharge divided by the 12-inch use estimate. Recharge coefficients calculated for 0.3, 1.2, 2.5, and 4 inches are 0.025, 0.1, 0.17, and 0.25, respectively. Slightly lower recharge estimates and sustained yield coefficients are used for Morton County, than for counties farther east because of somewhat lower (about 2 inches per year) average annual precipitation. In Morton County all of the shallow aquifers are variably confined and unconfined. All of the recharge coefficients on Table 3 are therefore 0.17.

Irrigation acreage based on sustainable water use is further adjusted by the water quality coefficient, which is the probability of obtaining water suitable for irrigation in a given well (Table 2, column 5). The most limiting parameter is used to adjust for water quality. The resulting irrigable acreage estimate based on recharge and water quality is in Table 2, column (8). **About 10,500** (10,513) **acres are estimated as potentially irrigable, based on estimates of available water of suitable quality for irrigation.**

Potential Irrigation Development from Ground Water in Morton County

The most limiting factor in Table 3 [water limiting (column 8); or soil limiting (column 11)] is used to estimate potential irrigation development from ground water in Morton County. For Morton County, water is most limiting in the Elm Creek, Heart River, St. James, and Square Butte aquifers, while suitable land is most limited in the Killdeer, Little Heart, Shields, and Sims aquifers. Aquifers having potential irrigation that totals less than 130 acres (one quarter-section center pivot acreage) are counted as 0. Based on Table 3, **about 9,000** (9,196) **acres are estimated as having potential for irrigation development from ground water in Morton County.** This compares with about 1,022 acres of current irrigation development.

Additional Comments

All of the aquifers considered for potential development have very low probabilities (33 to 45%) chance of obtaining good quality water for irrigation from a given well. Although development from such supplies is certainly possible, there are additional problems of finding suitable water which add to the expense and difficulty of development. In addition many of the buried valley aquifers are indicated to have likely pumping rates of less than 50 gpm in many locations. Such a slow rate of pumping would necessitate the manifolding of wells, and further complicate the process of development. Thus, **while irrigation development from ground water in Morton County is possible, it will likely be a slow, case by case process of expansion. The ground water supplies in Morton County are not likely situated for large-scale development in a short period of time.**

IRRIGATION DEVELOPMENT FROM SURFACE WATER IN GRANT AND MORTON COUNTIES

Most of the water used for irrigation in Grant and Morton Counties is from surface water sources. A map of land potentially irrigable using surface water in Grant County is shown on Figure Gr/Mo-5. Water permit allocations (shown on Table 1) are of two types, based on the presence or absence of federal involvement. Water permits issued without federal requirements total about 2,000 acres in Grant County (mostly from the Cannonball River and its tributaries), and about 5,500 acres in Morton County, of which most is from the Missouri River. Total non-federal irrigation using surface waters would likely total about 7,500 acres for Grant and Morton Counties combined.

The second type of water permit is that having federal limitations and controls. In Grant and Morton Counties one such permit is exemplified by USBR Water Permit No. 250B, which authorizes the use of water for up to 13,538 acres of irrigation. Water is to be supplied as releases from the Heart Butte Dam into the Heart River, for irrigation between Lake Tschida and the Missouri River. Requirements for use are the establishment of a water use contract with the USBR, and an evaluation and approval of soil suitability on the proposed irrigation tract. As of 1992 a "Finding Of No Significant Impact", or FONSI, was issued for development of up to 10,000 acres for irrigation, with the intention of obtaining a FONSI for the additional acreage at a later time, pending further assessment of impact.

As of 1992 irrigation from Heart Butte Dam releases included 2,537 acres irrigated by the Western Heart River Irrigation District, and 3,103 acres irrigated by the Lower Heart Irrigation Company. During 1991 through 1993 about 7,000 acres were irrigated from the these releases. Current use is divided into approximate halves between Grant and Morton Counties, and planned development

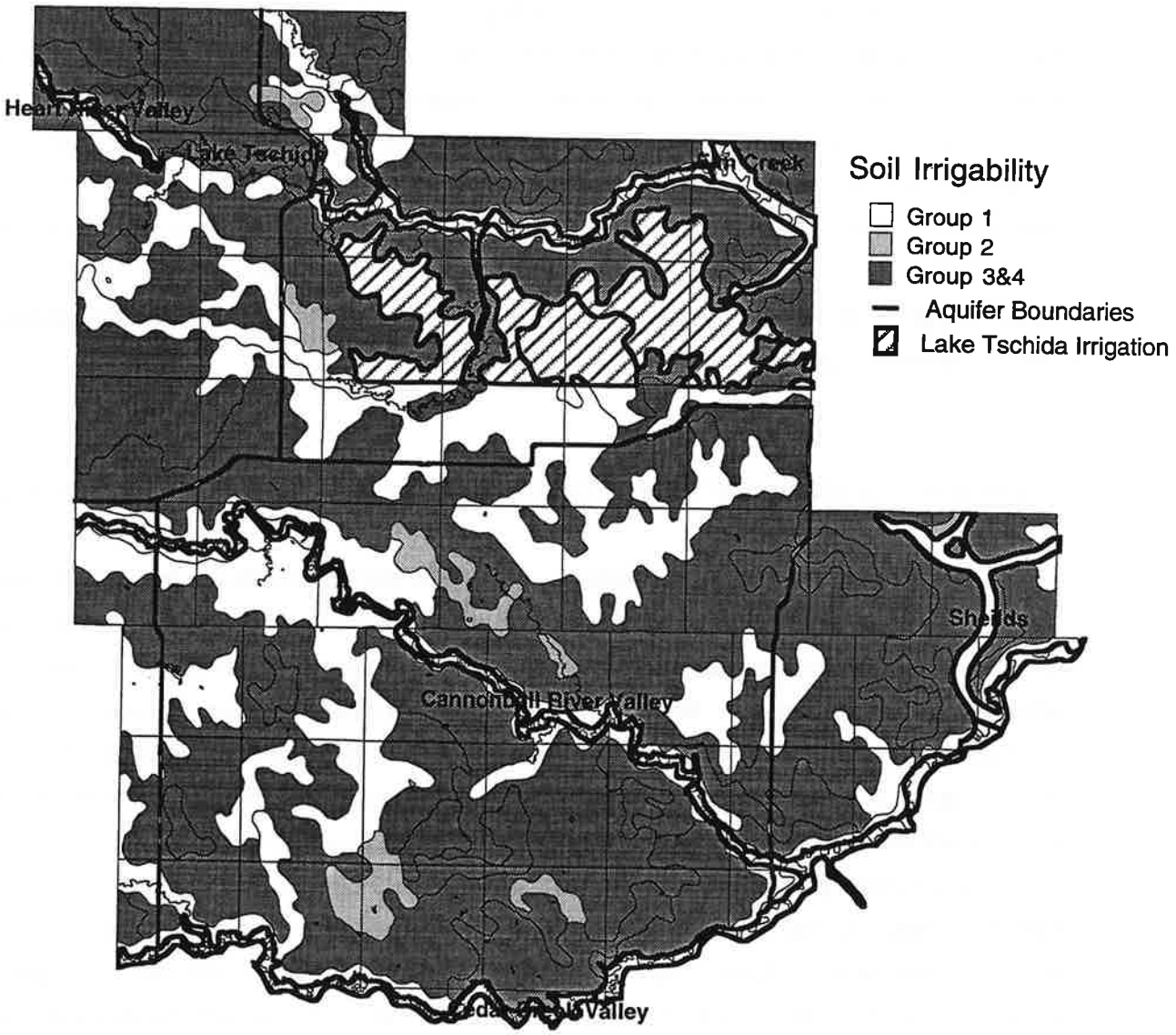

Figure Gr/Mo-5. Map of tracts of land in Grant County that may be developed for irrigation using water from the Heart River.

includes lands adjacent to the Heart River and Muddy Creek extending from the Heart Butte Dam to the Missouri River. Over and above current use, an additional 6,500 acres of land should be irrigable along the Heart River between Lake Tschida and the Missouri River, using Heart Butte Dam releases. **Total irrigation development in Grant and Morton Counties using water releases from the Heart Butte Dam should total at least 13,500 acres.**

Potential Irrigation Development from the Missouri River

In this report, the potential supply of water from the Missouri River for irrigation will be treated as essentially unlimited. Current irrigation development from the Missouri River in Morton County is confined to the lower terraces of the Missouri River. The total current irrigation from the Missouri River is about 4,000 acres (Table 1). Early plans for irrigation under the Heart River Unit of the Missouri River Project (USBR 1946) included about 38 80-acre irrigation units (about 4.75 sections) near the confluence of the Heart and Missouri Rivers. These tracts are potentially irrigable from either the Heart or the Missouri River. While the planned development has not occurred, some of the lands in this plan unit have been irrigated. For this report, an estimate of about 4 sections of potential irrigation will be used for this area. About 3 sections of Missouri River bottom land between Fort Lincoln State Park and Sugarloaf Butte are estimated to be suitable for irrigation. Irrigable bottom lands are estimated to total about 4,480 acres, which is close to the current permit allocation. Estimated total irrigation of bottom land is about 4,500 acres.

In addition, there appears to be one substantial tract of potentially irrigable land on Custer Flats. This potentially irrigable tract consists of about 9 sections (5,760 acres) bounded on the east by Highway 6, on the south by the southern boundary of T138 N, R 81/82 W; on the west by the imaginary north-south line running through the western boundary of T138 N R 82 W S34; and on the north by imaginary east-west line running through the northern boundary of T 138 N R 82 W S 13. A potential point of diversion from the Missouri River would be in T 138 N, R 81 W S 25. The route of water transport would follow the drainage course from Custer Flats to the Missouri River. The course is gradually sloped, and total static lift would not exceed 80 ft. The distance of transport to the nearest point of irrigation on Custer Flat would be about 3 miles, although there may be some possible irrigation along the route of transport. A map of potential irrigation development from the Missouri River in Morton County is shown on Figure Gr/Mo-6. A contingency factor of 1/2 is further applied to the approximate 6,000 acres of potentially irrigable land on Custer Flat, so that the final **estimated potential irrigation on Custer Flat would be about 3,000 acres. Total combined potential irrigation from the Missouri River in Morton County would be estimated to be about 7,500 acres.**

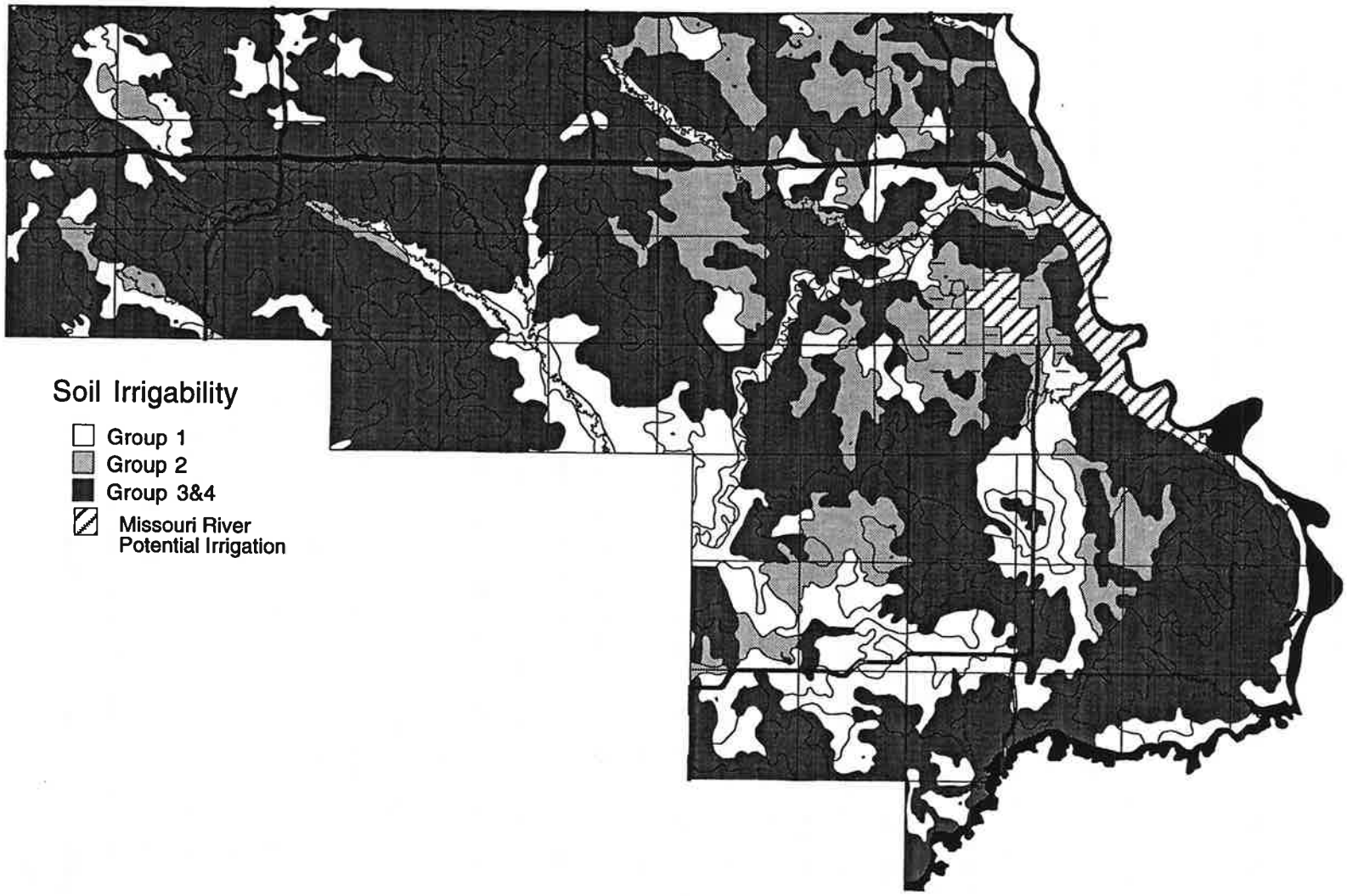

Figure Gr/Mo-6. Map of tracts of land in Morton County that may be developed for irrigation using water from the Missouri River, and from the Heart River.

Irrigation from Non Missouri River Surface Water Sources

About 3,500 acres in Grant and Morton Counties combined are permitted for irrigation from the Heart and Cannonball Rivers and their tributaries, without involvement in federal project development. Of this, about 1,500 acres (1,200 in Grant County and 300 in Morton County) are used as gravity, flood, or waterspreading, and a substantial portion of this is spring applied on hay crops. Much of this water might not be available as a reliable summer water supply. Thus, it is estimated that **about 2,000 acres of water currently permitted from surface water sources other than the Missouri River, and not dependent on federal project involvement, would be available for consistent irrigation use.**

Total Potential Irrigation Development From Surface Water

Total surface-water irrigation using waters not withdrawn from the Missouri River or from Heart Butte Dam as a part of the controlled releases contracted with the USBR are estimated to be about 2,000 acres. Total potential irrigation from the Missouri River is estimated to be about 7,500 acres. Total potential development using water releases from Heart Butte Dam are estimated to be at least 13,500 acres. **Total potential surface-water irrigation development is thus estimated at about 23,000 acres in Grant and Morton Counties combined.** This compares with about 7,000 acres currently permitted for irrigation use by the State of North Dakota, and about 7,000 acres of irrigation developed under USBR Water Permit No. 250 B.

Additional Comments

The contingency factor of 1/2 applied to Custer Flats has been applied to all potential surface-water development tracts in this study. **Close investigation of the potential irrigation development site on Custer Flats may indicate that considerably more land is available for development than is indicated here. This site is worth further investigation.**

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT

Total potential irrigation development using surface water is estimated at 23,000 acres for Morton and Grant Counties combined. Total irrigation development from ground water has been estimated at about 11,000 acres for Grant and Morton Counties combined. However, about 2,000 acres of this land is in the Heart River valley, and would likely overlap with potential irrigation from the Heart River. About 1,000 acres of the Elm Creek, Little Heart and Square Butte Creek aquifers would

likely overlap areas of potential surface-water irrigation from the Missouri River. Adjusted for surface-water source overlap, the potential ground-water development estimate is decreased to about 8,000 acres. One additional consideration, already discussed, is that of the inconsistent water quality and the variation in pumping rates from aquifers. Although these have been considered in the current estimates, there still remain additional problems in finding and developing irrigable water supplies, that have not been fully accounted for. It is thus thought that the 8,000 acre figure should be considered as an upper end of a range from about 5,000 to 8,000 acres of potential irrigation development using ground water. **The final estimate of total potential irrigation development would thus be in a range from about 28,000 to 31,000 acres for Grant and Morton Counties combined.**

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Potential Irrigation Development in Griggs County, North Dakota

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT FOR GRIGGS COUNTY

The single largest source of irrigation water in Griggs County is the Spiritwood aquifer, which underlies most of the western half of the county. About 32,000 acres overlying the Spiritwood and McVille aquifers have soils classified as irrigable or conditionally irrigable, have slopes of less than 3 %, are free from substantial surface and subsurface drainage requirements, and lie in parcels of sufficient size for irrigation. In this study, estimates of potentially irrigable land are based on total land classified as irrigable, multiplied by a contingency factor of 1/2 to account for potential error, and land owner preferences regarding development. The contingency factor is also intended to lend a conservative bias to this report. Application of the contingency factor results in an estimate of at least 16,000 acres of land in Griggs County that are suitable for irrigation, and overlie aquifers.

Water quality for irrigation is variable. About 70% of water samples collected from the Spiritwood aquifer are of suitable quality for irrigation, based on the criteria of this study. Estimates of long-term sustainable yield indicate that sufficient water for about 8,500 acres of irrigation is possible on a long-term basis.

Potential irrigation development is estimated by summing the most limiting resource (irrigable land or water) for each aquifer. **Results indicate that development of at least 8,000 acres for irrigation should be feasible in Griggs County.** Estimates of potential irrigation development in this report compare with a total of 7,484 acres currently permitted for irrigation in Griggs County. This estimate is likely conservative, and it would not be implausible that as much as double the projected acres might be developed in carefully monitored stages.

POTENTIAL IRRIGATION DEVELOPMENT IN GRIGGS COUNTY NORTH DAKOTA

The purpose of this report (chapter) is to provide an evaluation of land and water available for potential irrigation development in Griggs County. Methods of assessment used in this report were designed to provide a conservative estimate. These methods were described in a previous introductory section. It is emphasized that the findings of this report are based on general information. Estimates of irrigation potential are preliminary, and should not be used for individual project planning without further local in-depth analysis. For the sake of continuity in computation, data on computation tables are provided to the nearest digit. However, this should not lead to the conclusion that this report can estimate acreage with such a high level of precision. **In the text of this report, the final summary estimates resulting from table computations are rounded to the nearest 500 acres.** These final rounded numbers reflect more appropriately the general character of these estimates.

In Griggs County there are currently 33 irrigation permits for a total of 7,484 acres. There are an additional 1,000 acres (937 acres) that have been applied for but are not yet granted. Actual water use varies. Between 1991 and 1993 largest irrigated acreage was 5,586 in 1992. Least irrigation (2,277 acres) occurred in 1993, which was an extremely wet year. Almost all water permits in Griggs County are from ground water. There are only 40 acres permitted for irrigation using surface water.

IRRIGATION DEVELOPMENT FROM GROUND WATER

Assessment of potential irrigable land in this report will not be limited to or based on actual current water permits, or on current actual irrigated acreage. Rather it will be based on evaluation of the water and soil resource. In Griggs County two principal aquifers have been identified as potential sources for irrigation. These are listed on Table 1. There are two possible limiting factors affecting potential irrigation development using ground water. These are (1) irrigable land within practical distance of the water source , and (2) available water of suitable quality in close proximity to irrigable land.

Total Irrigable Soils

There are approximately 454,675 acres in Griggs County. According to a study conducted by North Dakota State University (NDSU) there are about 336,845 acres of irrigable and conditionally irrigable land in Griggs County (Omodt, written communication, 1982). About 79 % is classified as conditionally irrigable because of slope, drainage requirements, or slowness of internal drainage.

Table 1. Resources for potential irrigation development in Griggs County, ND. ECE is the electrical conductivity of water; SAR is the sodium adsorption ratio of water; and Boron is the concentration of boron in water. Potential irrigable acres based on water limitations (column 8) are calculated by multiplying the total acreage (column 7) by the recharge coefficient coefficient in column (6) as described in the text, and by adjusting for water quality (column 5). Land mapped in irrigable soils series, and having a slope of less than 3% (column 10) is calculated from land area mapped in irrigable associations overlying the aquifer (column 9), adjusted for the proportion of the association attributed to soils of irrigation suitable series, and by an adjustment factor (0.43) accounting for slopes greater than 3%. The final estimate of potential irrigation development (column 11), is half of column 10. **Bold type** indicates most limiting estimate of potential irrigation, used in final estimates of potential irrigation development. (c) means aquifer is confined with less than 50 feet of overburdon. (c†) means that aquifer is deeply confined, having more than 50 feet of overburdon. (u) means that aquifer is unconfined. (c/u) means that aquifer is variably confined and unconfined.

(1) WATER SOURCE	(2) ECE %<1500 µS/cm	(3) SAR %< 6	(4) BORON %<2 mg/L	(5) WATER QUALITY COEFFICIENT	(6) RECHARGE COEFFICIENT	(7) AREA OVERLYING AQUIFER acres	(8) POTENTIAL IRRIGABLE ACRES-WATER LIMIT acres	(9) LAND MAPPED IN IRRIGABLE ASSOCIATIONS acres	(10) LAND MAPPED IN IRRIGABLE SOIL SERIES, SLOPE < 3% acres	(11) POTENTIAL IRRIGABLE SOIL OVERLYING AQUIFER acres
McVille -c	85	82	99	0.82	0.07	9,632	**553**	9,312	1,641	821
Spiritwood-c†	80	70	100	0.7	0.05	212,288	**7,430**	138,726	30,422	15,211
undifferentiated	-	-	-	07*	0.07	11,328	555	320	105	53
Total						233,248	8,538	148,358	32,168	16,085

* Data missing. Use most limiting case for county.

The classification used in this report is a much more restrictive subset of that used in the NDSU study. A soil association map (USDA-SCS, unpublished) is provided on Figure Gr-1. All soils requiring extensive surface or internal drainage are excluded from consideration, and all soils having slopes of more than 3 % are also excluded. Using the criteria of this study, about 53,700 acres are classified as Group 1 (irrigable without limitations, slope less than 3 %) soils based on Griggs County SCS soil survey tabulations. There are an additional 11,085 irrigable acres in the Group 2 category (irrigable with limitations). Thus, based on soil suitability alone, there are about 64,785 acres of potentially irrigable land.

All federal, state, and municipal land is excluded from the potentially irrigable acres. There are about 15,343 acres of state and federal land, and about 5,760 acres of municipal land, for a total of about 21,103 acres of government land. About 14 % of all land in Griggs County is classified as irrigable according to standards of this study. Applying this proportion to government land gives 3,006 acres of excluded land that might be considered irrigable. After subtracting estimated irrigable government land, approximately **62,000** (61,788) **acres would be considered to be potentially irrigable based on soil factors alone.** A map of soil Groups (irrigable, conditionally irrigable, and non irrigable) as defined for this study is provided on Figure Gr-2.

Estimates of Irrigable Soil Overlying Aquifers

The overall estimates of irrigable soils discussed above were taken from soil survey summary tables and were adjusted for slopes greater than 3%. Estimates of irrigation-suitable soil overlying aquifers were calculated by integrating the areas of mapped soil associations within mapped aquifer boundaries. Area mapped to soil associations considered to be predominantly irrigable were adjusted by the percent of individual soil series within the association classified as irrigable. In addition, irrigable series were adjusted to account for slopes greater than 3% using a factor of 0.43. Griggs County soil summary table data indicated that about 43 % of soils mapped in series considered irrigable, had slopes of less than 3 %. Finally, a 1/2 contingency factor was applied to all estimates of irrigable soil area. Results in Table 1, column 11, indicates that **about 16,000 acres** (16,085 acres) **of land overlying aquifers would be considered as potentially irrigable based on soil suitability alone**. A small portion of potential development overlies the McVille aquifer. But most of the potential development is from the Spiritwood aquifer. Most of the irrigable soils mapped were in Group 1 (irrigable without limitations).

Irrigable Land Overlying Aquifers Based on Water Supply Limitations

Ground-water resources in Griggs County have variable quality for irrigation use. Between 70 and 100 % of the ground water from aquifers considered on Table 1 are of suitable quality for

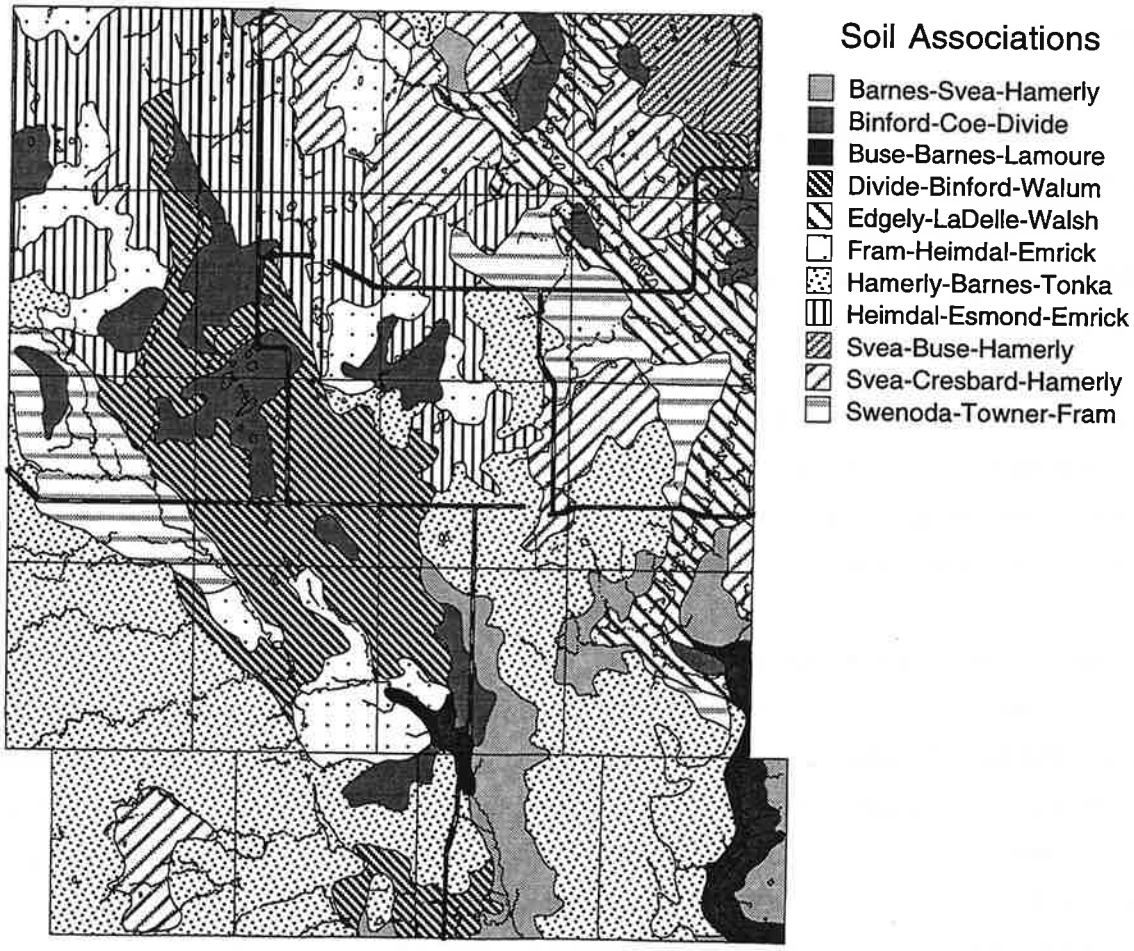

Figure Gr-1. Soil association map of Griggs County ND. (From Griggs County Soil Survey, USDA-SCS , unpublished, 1995).

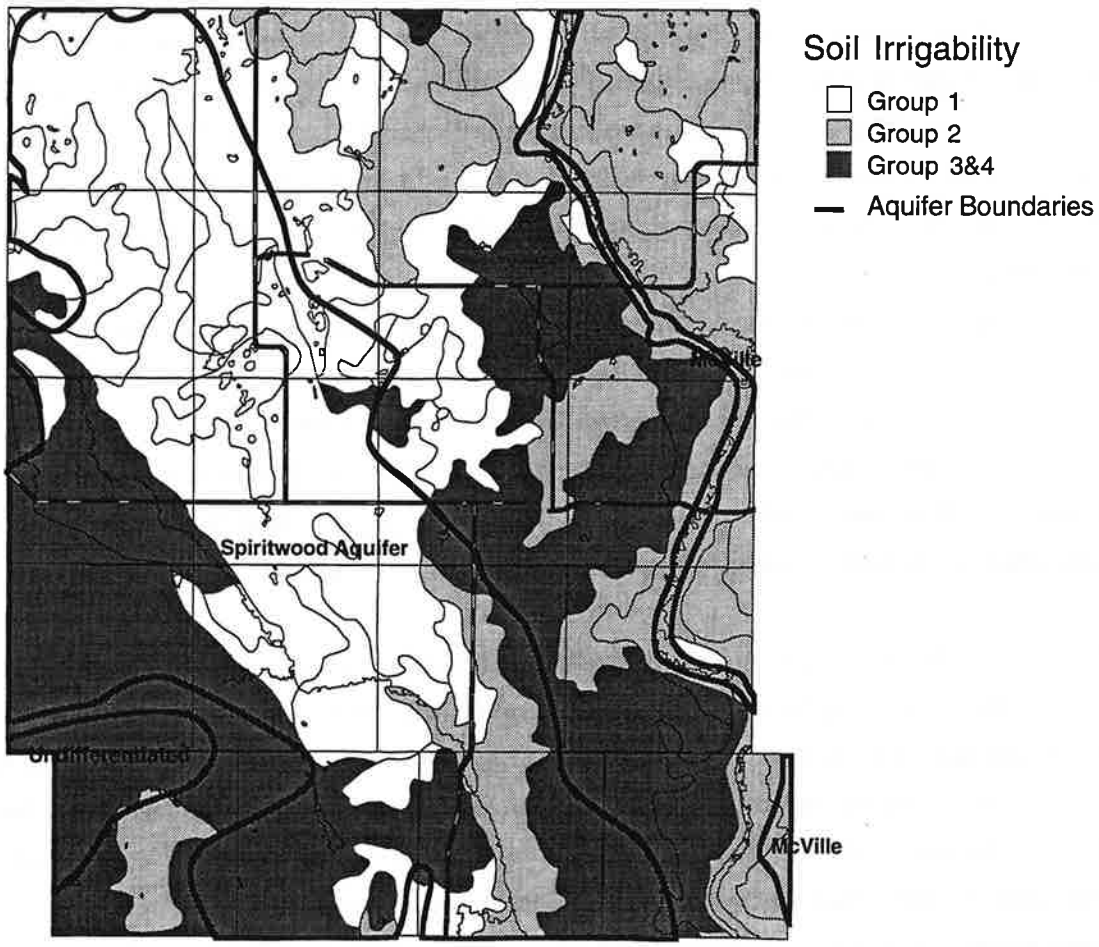

Figure Gr-2. Map of boundaries of the principal aquifers in Griggs County, ND. (From Downey and Armstrong 1977).

irrigation. Water quality is evaluated on the basis of suitable electrical conductivity (ECE), sodium adsorption ratio (SAR), and Boron concentration (Table 1). Estimates of water available for potential irrigation are based on an estimated recharge of 0.3 inches per year for deeper confined aquifers in glacial till, 1.2 inch per year for shallow confined aquifers, 2.5 inches per year for aquifers that are partly confined, and partly unconfined, and 4 inches per year for unconfined aquifers. Irrigable acreage for each aquifer is then calculated by assuming an average of 12 inches per acre per year irrigation. The recharge coefficient is the estimated recharge divided by the 12-inch use estimate. Recharge coefficients calculated for 0.3, 1.2, 2.5, and 4 inches are 0.025, 0.1, 0.21, and 0.33, respectively. In some cases, depending on the aquifer, ranges of values between these coefficients are selected.

Irrigation acreage based on sustainable water use is further adjusted by the water quality coefficient, which is the probability of obtaining water suitable for irrigation in a given well (Table 1, column 5). The most limiting parameter (of ECE, SAR, Boron) is used to adjust for water quality. The resulting irrigable acreage estimate based on recharge and water quality is in Table 1, column (8). **About 8,500 acres** (8,538 acres) **are estimated as potentially irrigable, based on estimates of available water of suitable quality for irrigation.**

Potential Irrigation Development from Ground Water in Griggs County

The most limiting factor in Table 1 [water limiting (column 8); or soil limiting (column 11)] is used to estimate potential irrigation development from ground water in Griggs County. Parcels of land less than 130 acres are not included in the sum of potentially irrigable acres. **Development from both the Spiritwood and Mcville aquifers is limited by water rather than available soil. The sum of potentially irrigable acres based on the most limiting resource is about 8,000 acres** (7,983 acres). This compares with about 7,500 acres already permitted for irrigation in Griggs County.

Additional Comments

It is considered that the estimate of 8,000 acres of irrigation development (of which about 7,500 acres are already developed) is conservative, and that substantial additional development would be possible. The Spiritwood aquifer is very extensive in Griggs County. It is not implausible that in some areas recharge to the Spiritwood aquifer might exceed the estimates used in this report. However, lacking further information, this cannot be stated with certainty. Moreover, for a large aquifer, like the Spiritwood, a substantial amount of development might be allowable on the basis of limited mining, and might be sustainable for many years if not indefinitely. On the basis of limited mining it may be feasible to double the estimated 8,000 acres. The possibility of further development,

or limited mining of water would have to be considered on a case by case basis. Such development would likely occur in gradual, well monitored stages.

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT

Approximately 8,000 acres of potential irrigation, all from ground water, appears to be available for development in Griggs County. A doubling of the potential irrigated acres might be feasible under appropriate conditions, but would likely have to be implemented in carefully monitored stages.

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Potential Irrigation Development in Kidder County, North Dakota

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT FOR KIDDER COUNTY

Kidder County has limited external drainage, and a substantial ground-water resource. About 385,000 acres overlie a complex of confined and unconfined aquifers. Of this about 52,000 acres overlying aquifers have soils classified as irrigable or conditionally irrigable, have slopes of less than 3 %, are free from substantial surface and subsurface drainage requirements, and lie in parcels of sufficient size for irrigation. In this study, estimates of potentially irrigable land are based on total land classified as irrigable, multiplied by a contingency factor of 1/2 to account for potential error, and land owner preferences regarding development. The contingency factor is also intended to lend a conservative bias to this report. Application of the contingency factor results in an estimate of at least 26,000 acres of irrigable land in Kidder County.

There is substantial water for irrigation development in Kidder County. Most of the ground water is of good quality, with low sodium adsorption ratio, electrical conductivity, and boron content. Estimates of long-term sustainable yield indicate that sufficient water for about 50,500 acres of irrigation is likely on a long-term basis.

Potential irrigation development is estimated by summing the most limiting resource (irrigable land or water) for each aquifer. **Results indicate that development of at least 26,000 acres for irrigation should be feasible in Kidder County.** Under optimal conditions potential irrigation development may be as much as double this estimate. The greatest potential for irrigation development appears to be from the unconfined Marstonmoor Plain and Tappen aquifers, and from the extensive confined Kidder County aquifer complex. Estimates of potential irrigation development in this report compare with a total of 11,410 acres currently permitted for irrigation in Kidder County as of April, 1995.

POTENTIAL IRRIGATION DEVELOPMENT IN KIDDER COUNTY NORTH DAKOTA

The purpose of this report (chapter) is to provide an evaluation of land and water available for potential irrigation development in Kidder County. Methods of assessment used in this report were designed to provide a conservative estimate. These methods were described in previous introduction and methods sections. It is emphasized that the findings of this report are based on general information. They are preliminary in nature, and they should not be used for individual project siting without further local in-depth analysis. For the sake of continuity in computation, data in tables are provided to the nearest digit. However, this should not lead to the conclusion that this report can estimate acreage with such a high level of precision. **In the text of this report, the final summary estimates resulting from table computations are rounded to the nearest 500 acres.** These final rounded numbers reflect more appropriately the general character of these estimates.

Current Irrigation Water Permits and Water Use

In Kidder County there are currently 11,410 acres approved for irrigation. Of this, actual use varies roughly between 2,000 and 8,000 acres, depending upon the wetness of the year. In most years, irrigation is likely greater than 7,000 acres. Almost all of the water permits are for ground-water. Only 382 acres have been approved for irrigation using surface water. Of this, only half were irrigated from 1991 through 1993. Kidder County has very poorly defined external drainage, so that there are no major streams to provide a reliable surface water supply.

A large portion of the county is covered with lakes and ephemeral potholes. These, however, do not provide reliable supplies of water in most cases. Because of the complexities involved with lake hydrology and competing recreational and wildlife interests, surface waters in Kidder County are excluded from consideration as sources. While some lake waters would likely be available for use, they would have to be considered as individual cases.

IRRIGATION DEVELOPMENT FROM GROUND WATER

Assessment of potential irrigable land in this report will not be limited to or based on actual current water permits, or on current actual irrigated acreage. Rather it will be based on evaluation of the water and soil resource. In Kidder County three principal aquifers have been identified as potential sources for irrigation. These are listed on Table 1. There are two possible limiting factors

Table 1. Resources for potential irrigation development in Kidder County, ND. Potential irrigable acres based on water limitations (column 8) are calculated by multiplying the total acreage (column 7) by the recharge coefficient coefficient in column (6) as described in the text, and by adjusting for water quality (column 5). Land mapped in irrigable soils series, and having a slope of less than 3% (column 10) is calculated from land area mapped in irrigable associations overlying the aquifer (column 9), adjusted for the proportion of the association attributed to soils of irrigation suitable series (0.6), and by an adjustment factor (0.3) accounting for slopes greater than 3% and for field discontinuity caused by potholes (Column 10). A contingency and error factor of 1/2 is applied to the final estimate (column 11) of irrigable land. **Bold numbers** in columns (8) and (11) are used to compute final estimated total potential irrigation development. (-c) indicates confined aquifer. (-u) indicates unconfined aquifer.

(1) WATER SOURCE	(2) ECE %<1500 µS/cm	(3) SAR %< 6	(4) BORON %<2 mg/L	(5) WATER QUALITY COEFFICIENT	(6) RECHARGE COEFFICIENT	(7) AREA OVERLYING AQUIFER acres	(8) POTENTIAL IRRIGABLE ACRES-WATER LIMIT acres	(9) LAND MAPPED IN IRRIGABLE ASSOCIATIONS acres	(10) LAND MAPPED IN IRRIGABLE SOIL SERIES, SLOPE < 3% acres	(11) POTENTIAL IRRIGABLE SOIL OVERLYING AQUIFER acres
Kidder County -c	85	88	99	0.85	0.1	343,168	21,740 **	289,884	38,142***	**19,071*** **
Kunkle Lake * -u	-	-	-	.99	0.33	4,499	1,484	3,059	550	**275**
Marstonmoor -u	99	99	100	0.99	0.33	33,856	11,172	33,856	6,094	**3,047**
Robinson * -u	-	-	-	.99	0.33	8,332	2,750	8,332	610	**305**
Tappen-u	100	100	100	1.0	0.33	40,710	13,434	37,670	6,780	**3,390**
Total	94	88	99	0.88			50,581	289,884***	52,176***	26,088

* No water quality data were available. Used probability of most limiting case.
** Computations are made from total area minus area of unconfined aquifers.
*** Almost all surface area of the unconfined aquifers, overlies the confined Kidder County aquifer. Unconfined aquifer thickness is not counted in total to avoid duplication.

affecting potential irrigation development using ground water. These are (1) irrigable land within practical distance of the water source , and (2) available water of suitable quality in close proximity to irrigable land.

Total Irrigable Soils

There are approximately 867,953 acres in Kidder County. A soil association map of Kidder County (USDA-SCS, 1988) is provided on Figure Ki-1. A study of Kidder County conducted by North Dakota State University (NDSU), provided by Omodt (1982, written communication), indicates that a total of 627,000 acres are mapped as irrigable or conditionally irrigable.

The criteria used in this study consist of a much more restrictive subset of the criteria used in the NDSU study. All soils requiring surface, or subsurface drainage are excluded, and all soils having slopes greater than 3% are excluded. Applying the criteria of this study to the soil survey table of area mapped to individual series (USDA-SCS, 1988), there are an estimated 102,924 acres of Group 1 (irrigable without limitations, slope less than 3 %) soils, and an additional 30,100 irrigable acres in the Group 2 category (irrigable with limitations). In most cases excessive slope is the limit in Kidder County. Another limitation is fineness of soil, which requires controlled rates of water application. Soils requiring extensive surface or subsurface drainage are considered as non irrigable in this study. Thus, based on soil suitability alone, there are about 133,024 acres of potentially irrigable land.

Federal, state, and municipal land is excluded from the estimates of potentially irrigable acres. Estimates of federal and state lands (37,409 acres) and town lands (5,120 acres) total 42,529 acres. About 15 % of all land in Kidder County is irrigable. Using this proportion, the irrigable portion of government land (15 %, or 6,379 acres) is subtracted from total irrigable land. It is estimated that there are **about 126,500 acres** (126,625 acres) **of potentially irrigable land in Kidder County based on soil suitability alone.**

Irrigable Land Overlying Kidder County Aquifers

Kidder County has a large aquifer complex, consisting of both confined and unconfined aquifers. About 343,168 acres overlie the Kidder County aquifer complex. Approximate aquifer boundaries are shown on Figure Ki-2. A map of soil suitability for irrigation is also shown on Figure Ki-2. Most soils suitable for irrigation overlie the Kidder County aquifer complex.

For most counties in central North Dakota, the method of this study has been to (1) determine total acreage in individual soil associations overlying an aquifer; (2) calculate the amount of irrigable land by applying the percent of each association attributed to soil series that meet irrigability criteria; (3) adjust for slope; and (4) multiply by a contingency factor of 1/2. In the case of Kidder County, an

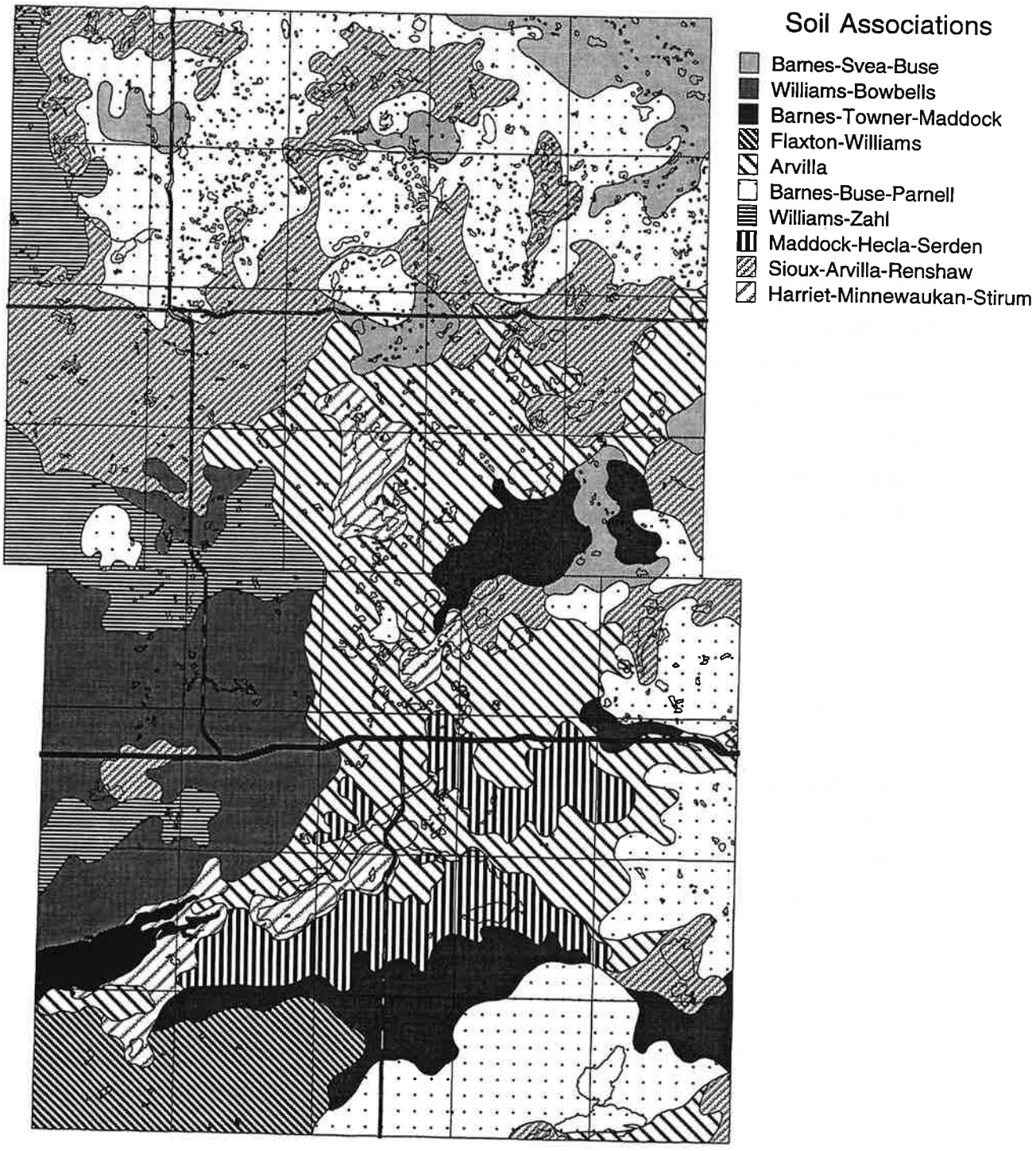

Figure Ki-1. Soil association map of Kidder County ND. (From Kidder County Soil Survey, USDA-SCS 1988).

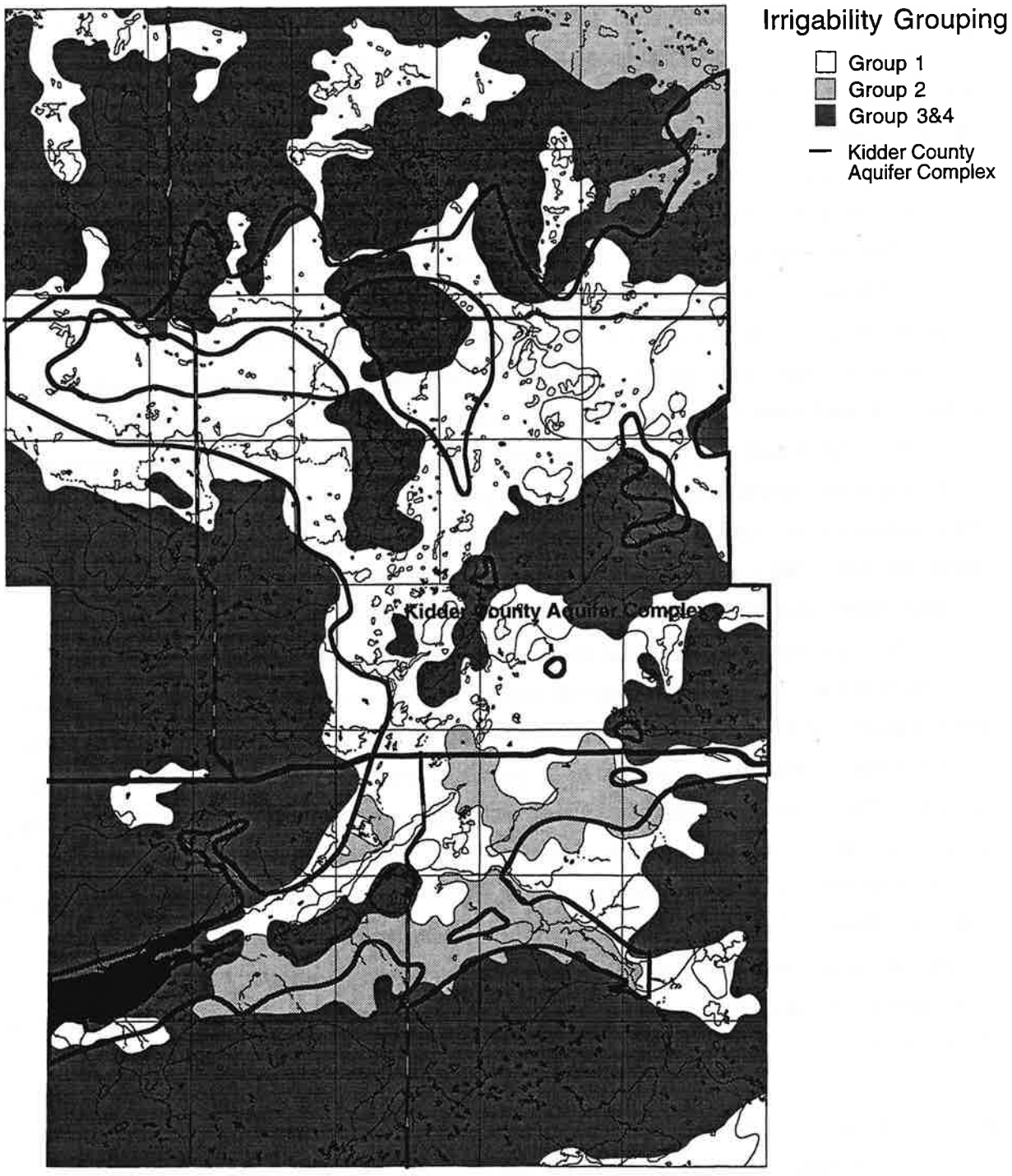

Figure Ki-2. Map of boundaries of the predominantly confined Kidder County aquifer complex, Kidder County, ND. (From Larson, 1987).

additional factor must be considered. In Kidder County, not only the total amount of irrigable land, but the lay of that land must be considered. Because of the large numbers of lakes and potholes, there are substantial amounts of land in soil classes suitable for irrigation, that are located in scattered parcels divided by surface water bodies. Such parcels are not suitable for irrigated farming. For example, if a Sioux-Arvilla-Renshaw association is found to have 60% of its land in irrigable classes, that still does not mean that all of that land will be in parcels large enough to irrigate.

For this reason, a different method for computing irrigable soil overlying the aquifer was used for Kidder County. Soil survey photographic maps (USDA-SCS, 1988) were examined for quarter-sections sufficiently free from ponds to allow for the use of a center-pivot irrigation unit. A total of 204 sections were examined in groups of twelve or fifteen sections each (fourteen samples), by two judges. For each section, a number of irrigable quarter sections was assigned based on current land use, distribution of potholes, and apparent slope. Results indicated that the mean fraction of total land suitable for irrigation was 0.38, with a standard error of 0.038 (range 0.08 to 0.58). We can be 95% certain that the fraction of soil in parcels suitable for irrigation is between 0.30 and 0.46. This compares with a factor of 0.6 that would be used based on percentages of soil series in the soil association definition. For this study, the lower (0.3) factor will be used.

Total land overlying the Kidder County aquifer complex (343,168) is adjusted for Long Lake acreage (7,667 acres), and soil mapped non irrigable according to the classification used in this study (45,617 acres). The result (289,884 acres) is adjusted according to the fraction (0.6) of the mapped association attributed to series classified as "irrigable". A further adjustment is made for the fraction of quarter sections considered irrigable (0.3) and a contingency factor of 1/2 to give a final estimate of about 26,090 acres. In Table 1, column 11, surface area overlying unconfined aquifers is not added in the final sum because unconfined aquifers almost entirely overlie the confined Kidder County aquifer complex. Based on irrigation suitability of soil overlying aquifers, **about 26,000 acres of land might be developed for irrigation in Kidder County** (column 11). If the error and contingency factor were not applied potential irrigable land overlying aquifers might be as much as 50,000 acres.

Irrigable Land Overlying Aquifers Based on Water Supply Limitations

Ground-water resources in Kidder County are locally unique in extent, quality, sustainability, and correlation with overlying soils having good irrigation potential. A large portion (about 385,920 acres) of Kidder County overlies coarse buried glacial deposits that comprise the Kidder County aquifer complex (Figure Ki-2). Most of the Kidder County aquifer complex is confined. However, part of the Kidder County aquifer complex is overlain by surficial unconfined aquifers of glacial origin.

Some of the major surficial aquifers include the Kunkel Lake, Marstonmoor Plain, Robinson, and Tappen aquifers (Table 1). Unconfined aquifers are shown on Figure Ki-3.

The hydrology of Kidder County is marked by lack of external drainage. This means that little precipitation leaves the county, except through evaporation. The large extent of the "more or less connected" coarse deposits is also conducive to redistribution of recharge waters within the aquifer (Larson, 1987). Under current conditions of water allocation and use, ground water in Kidder County appears to be well buffered from immediate fluctuations in climate and water use. Observations of wells in Kidder County during the drought year of 1988, indicated almost no recession in water levels. Moreover, under the current level of water appropriation there has been no observed residual drawdown in Kidder County aquifers (personal communication, Kevin Swanson, April 1995). These conditions indicate that substantial recharge is occurring, and that a relatively large sustained level of use might be possible.

In contrast to neighboring counties, water quality in most current wells is suitable for irrigation. The percent of wells having suitable quality water based on electrical conductivity (ECE), sodium adsorption ratio (SAR), and boron is shown on Table 1 for different portions of the aquifer. For the buried Kidder County aquifer complex, a limiting water quality coefficient of 0.85 is used. For all unconfined aquifers, a coefficient of 1.0 is used.

There are about 87,397 acres overlying the unconfined aquifers listed in Table 1. There is no reduction in potential water use due to inadequate water quality. Common estimates of recharge for similar soils in eastern North Dakota (Dickey and Sargent Counties) are about 4 to 5 inches per year. In Kidder County, average annual precipitation is about 3 inches less than in the eastern part of the state. However, the lack of external drainage in Kidder County enhances likelihood of substantial local recharge. Because of these offsetting factors, a recharge estimate of 4 inches per year is used for unconfined aquifers. A sustainable yield of 1/3 of total acres overlying the unconfined aquifers acreage is used, based on an average water use of 12 inches per year. Results indicate that there probably exists a supply of water sufficient to irrigate about 28,840 acres.

Most unconfined aquifers are mapped within the boundaries of the overall Kidder County aquifer complex. Areas mapped to unconfined aquifers are subtracted from the total estimated area of the aquifer complex, to provide an estimate (298,523 acres) of land underlain by confined aquifer. For confined units sustainable yield was calculated using an estimate of 1.2 inches of recharge water per year. This was computed by an adjustment factor of 1/10 of total acreage overlying the aquifer. The resulting estimate is 29,852 acres. Applying a limiting water quality coefficient of 0.85 for the confined units, gives 25,374 acres of land potentially irrigable based on water limitations.

From these estimates, **a total of about 50,500 acres might be developed for irrigation in Kidder County,** based on water supply and water quality limitations. One additional

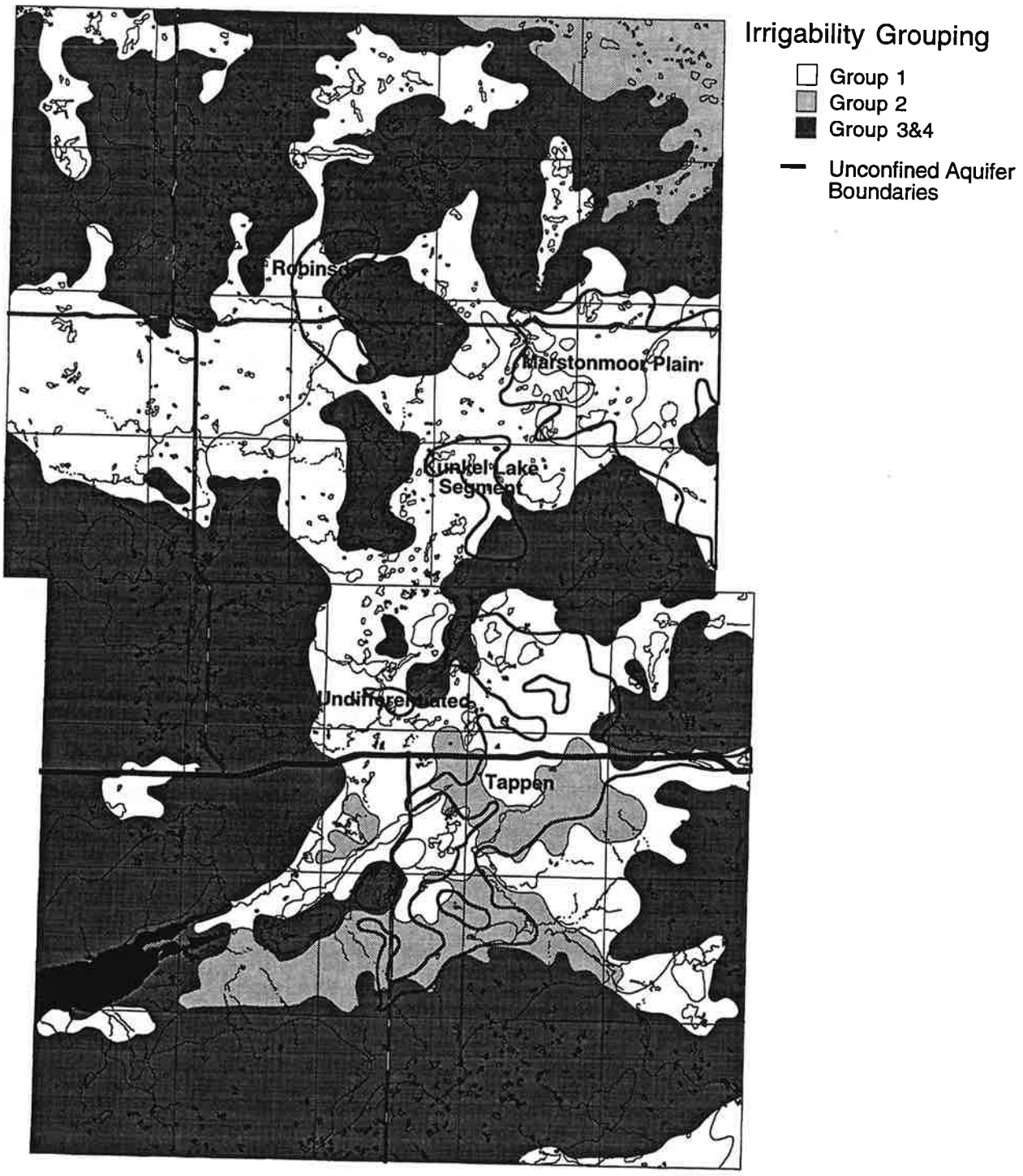

Figure Ki-3. Map of boundaries of the predominantly unconfined confined Kunkel Lake, Marstonmoor, Robinson, and Tappen aquifers, Kidder County, ND. (From Larson, 1987).

factor affecting development of unconfined aquifers in Kidder County is limited saturated thickness in some areas. Planners should be aware of the possible need for manifolded wells to supply a quarter-section center pivot, and in some instances irrigation will simply not be feasible because of inadequate pumping capacity.

Total Potential Irrigation Development From Aquifers

Potential irrigation development is calculated using the most limiting of the above criteria. If the overlying soil is most limiting, soil criteria are used (Table 1, column 11). If water supply is limiting, the water supply criterion is used (Table 1, column 8). **The estimated total potential irrigation development from aquifers is about 26,000** (26,088) **acres.** If the 1/2 contingency factor were not applied to irrigable land limitations, the estimated total might be as large as 50,000 acres. Current total land permitted for irrigation is about 11,500 acres, and the range of actual use is between 2,000 and 8,000 acres, with predominant use between 7,000 and 8,000 acres. There thus appears to be potential for an increase of at least 14,000 irrigated acres beyond current permitted acreage.

Additional Comments

Potential limits of irrigation development presented in this study are based on shortage of irrigable land rather than insufficient water. The estimate of total available water for irrigation is nearly double that of the available land (Table 1). Moreover, cited limitations on available water are based on estimates of long-term sustainable yield, calculated from recharge computations. In some instances controlled mining of water may be allowable. If the aquifer is large enough, mining of water could provide for substantial additional irrigation for a considerable period of time. Such limited mining of water would have to be considered on a case by case basis. Since land is the primary limiting factor, it should also be remembered that a contingency factor of 1/2 to account for error and for landowner preference has been applied. This factor may be large. Also, the 3% slope limit used in this study, and the "no drainage" assumption are conservative. Larger slopes could be irrigated in some cases, and use of surface and tile drainage could increase the amount of irrigable land.

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT

Approximately 26,000 acres appear to be suitable for irrigation development in Kidder County. Under optimal conditions, irrigation development may be feasible for as much as double this estimate.

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Potential Irrigation Development in Logan County, North Dakota

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT FOR LOGAN COUNTY

Three aquifers in Logan County provide most of the water for potential irrigation development. These are the Hillsburg, the Napoleon, and the Streeter aquifers. About 31,000 acres overlying these aquifers have soils classified as irrigable or conditionally irrigable, have slopes of less than 3 %, are free from substantial surface and subsurface drainage requirements, and lie in parcels of sufficient size for irrigation. In this study, estimates of potentially irrigable land are based on total land classified as irrigable, multiplied by a contingency factor of 1/2 to account for potential error, and land owner preferences regarding development. The contingency factor is also intended to lend a conservative bias to this report. Application of the contingency factor results in an estimate of at least 6,500 acres of irrigable land in Logan County.

Water quality for irrigation is mostly good. The percent of water of suitable quality for irrigation is usually greater than 90% for major aquifers. Estimates of long-term sustainable yield indicate that sufficient water for about 13,500 acres of irrigation is possible on a long-term basis.

Potential irrigation development is estimated by summing the most limiting resource (irrigable land or water) for each aquifer. **Results indicate that development of at least 6,500 acres for irrigation should be feasible in Logan County.** Potential for irrigation from surface water in Logan County is not substantial, and would not significantly alter this estimate. Estimates of potential irrigation development in this report compare with a total of 2,410 acres currently permitted for irrigation in Logan County. Estimated potential irrigation development is likely conservative, and it would not be implausible that substantial additional acres of irrigation might be developed in carefully monitored stages.

POTENTIAL IRRIGATION DEVELOPMENT IN LOGAN COUNTY NORTH DAKOTA

The purpose of this report (chapter) is to provide an evaluation of land and water available for potential irrigation development in Logan County. Methods of assessment used in this report were designed to provide a conservative estimate. These methods were described in a previous introductory section. It is emphasized that the findings of this report are based on general information. They are preliminary in nature, and they should not be used for individual project siting without further local in-depth analysis. For the sake of continuity in computation, data in computation tables are provided to the nearest digit. However, this should not lead to the conclusion that this report can estimate acreage with such a high level of precision. **In the text of this report, the final summary estimates resulting from table computations are rounded to the nearest 500 acres.** These final rounded numbers reflect more appropriately the general character of these estimates.

In Logan County, the primary source of irrigation water is ground water. Logan County has poorly defined external drainage, so that there are no major streams to provide a reliable surface water supply. While there are lakes and ephemeral potholes, these do not provide reliable supplies of water in most cases . In Logan County there are currently 2,410 approved acres for irrigation, in 18 permits. Of this, actual use varies roughly from between 1,264 and 1,788 acres, depending upon the wetness of the year. Only 235 acres have been approved for irrigation using surface water. Of this, not more than 30 acres were irrigated in any one year between 1991 and 1993.

Because of the lack of major streams, and because of the complexities involved with lake hydrology and competing recreational and wildlife interests, surface waters in Logan County are excluded from consideration as sources. While some lake waters would likely be available for use, they would have to be considered as individual cases. Lakes should not be considered as a potential large source of water in Logan county. In this study, potential surface-water irrigation is considered negligible. All potential irrigation will be analyzed using ground-water sources.

IRRIGATION DEVELOPMENT FROM GROUND WATER

Assessment of potential irrigable land in this report will not be limited to or based on actual current water permits, or on current actual irrigated acreage. Rather it will be based on evaluation of the water and soil resource. In Logan County two principal aquifers have been identified as potential sources for irrigation. These are listed on Table 1. There are two possible limiting factors affecting

Table 1. Resources for potential irrigation development in Logan County, ND. EC is the electrical conductivity of water; SAR is the sodium adsorption ratio of water; and Boron is the concentration of boron in water. Potential irrigable acres based on water limitations (column 8) are calculated by multiplying the total acreage (column 7) by the recharge coefficient coefficient in column (6) as described in the text, and by adjusting for water quality (column 5). Land mapped in irrigable soils series, and having a slope of less than 3% (column 10) is calculated from land area mapped in irrigable associations overlying the aquifer (column 9), adjusted for the proportion of the association attributed to soils of irrigation suitable series, and by an adjustment factor (0.56) accounting for slopes greater than 3%. The final estimate of potential irrigation development is half of column 10. **Bold type** indicates most limiting estimate of potential irrigation, used in final estimates of potential irrigation dev elopment. (c) indicates a confined aquifer, (c†) indicates deep (> 50 ft.) confining layer, (u) is an unconfined aquifer, and (c/u) is variably confined and unconfined.

(1) WATER SOURCE	(2) ECE %<1500 µS/cm	(3) SAR %< 6	(4) BORON %<2 mg/L	(5) WATER QUALITY COEFFICIENT	(6) RECHARGE COEFFICIENT	(7) AREA OVERLYING AQUIFER acres	(8) POTENTIAL IRRIGABLE ACRES-WATER LIMIT acres	(9) LAND MAPPED IN IRRIGABLE ASSOCIATIONS acres	(10) LAND MAPPED IN IRRIGABLE SOIL SERIES, SLOPE < 3% acres	(11) POTENTIAL IRRIGABLE SOIL OVERLYING AQUIFER acres
Beaver Lake * -c/u	-	-	-	0.9	0.1	7,123	641	0	0	**0**
Hillsburg * -u	-	-	-	0.9	0.33	16,371	4,862	7,200	2,708	**1,354**
McIntosh - c†	90	100	100	0.9	0.05	5,414	244	960	361	**181**
Napoleon - c/u	95	95	100	0.95	0.21	17,926	3,576	7,520	2,829	**1,414**
Streeter - u	95	95	100	0.95	0.33	18,867	5,914	14,406	6,602	**3,301**
Wishek-u	-	-	-	0.9	0.33	800	237	800	301	**151**
Total						66,501	13,474	30,886	12,801	6,401

* No water quality data were available. Used probability of most limiting case.

potential irrigation development using ground water. These are (1) irrigable land within practical distance of the water source, and (2) available water of suitable quality in close proximity to irrigable land.

Total Irrigable Soils

There are approximately 631,720 acres in Logan County. According to a study conducted by North Dakota State University (NDSU) there are about 303,487 acres of irrigable and conditionally irrigable land in Logan County (Omodt, written communication, 1982). About half is classified as conditionally irrigable because of slope, drainage requirements, or slowness of internal drainage.

The classification used in this report is a much more restrictive subset of that used in the NDSU study. A soil association map (USDA-SCS, unpublished 1995) is provided on Figure Lo-1. All soils requiring extensive surface or internal drainage are excluded from consideration, and all soils having slopes of more than 3 % are also excluded. Using the criteria of this study, about 40,976 acres are classified as Group 1 (irrigable without limitations, slope less than 3%) soils based on Logan County SCS soil survey tabulations. There are an additional 27,012 irrigable acres in the Group 2 category (irrigable with limitations). Usually the limitation is fineness of soil, which requires limited rates of water application. Soils requiring extensive surface or subsurface drainage are considered as non irrigable in this study. Thus, based on soil suitability alone, there are about 67,988 acres of potentially irrigable land. All federal, state, and municipal land is excluded from the potentially irrigable acres, except for state school lands of which 50% are excluded. Estimates of federal and state lands are approximately 16,989 acres, and town lands are estimated at 3,200 acres. The total of excluded land is 20,189 acres. It is estimated that there are **about 47,799 acres of potentially irrigable land in Logan County based on soil suitability alone.** A map of soil Groups (irrigable, conditionally irrigable, and non irrigable) as defined for this study is provided on Figure Lo-2.

Irrigable Land Overlying Logan County Aquifers

Logan County has substantial ground water. About 66,501 acres overlie aquifers in Logan County (Table 1). Approximate aquifer boundaries are shown on Figure Lo-2. A map of soil suitability for irrigation is also shown on Figure Lo-2. About 30,886 acres of land located overlying aquifers are mapped as belonging to soil associations that are predominantly irrigable. Potential irrigable soil overlying aquifers in Logan County is calculated by multiplying the area mapped to soils of irrigable associations by the percent of area within the association attributed to irrigation suitable soils series, and by an adjustment factor of 0.56 to account for slopes of more than 3%. The slope factor was computed as the ratio of the area of all irrigable soils in Logan County having slopes of less than 3%, divided by the total area of soils in irrigable series in the county. The result for Logan County is about

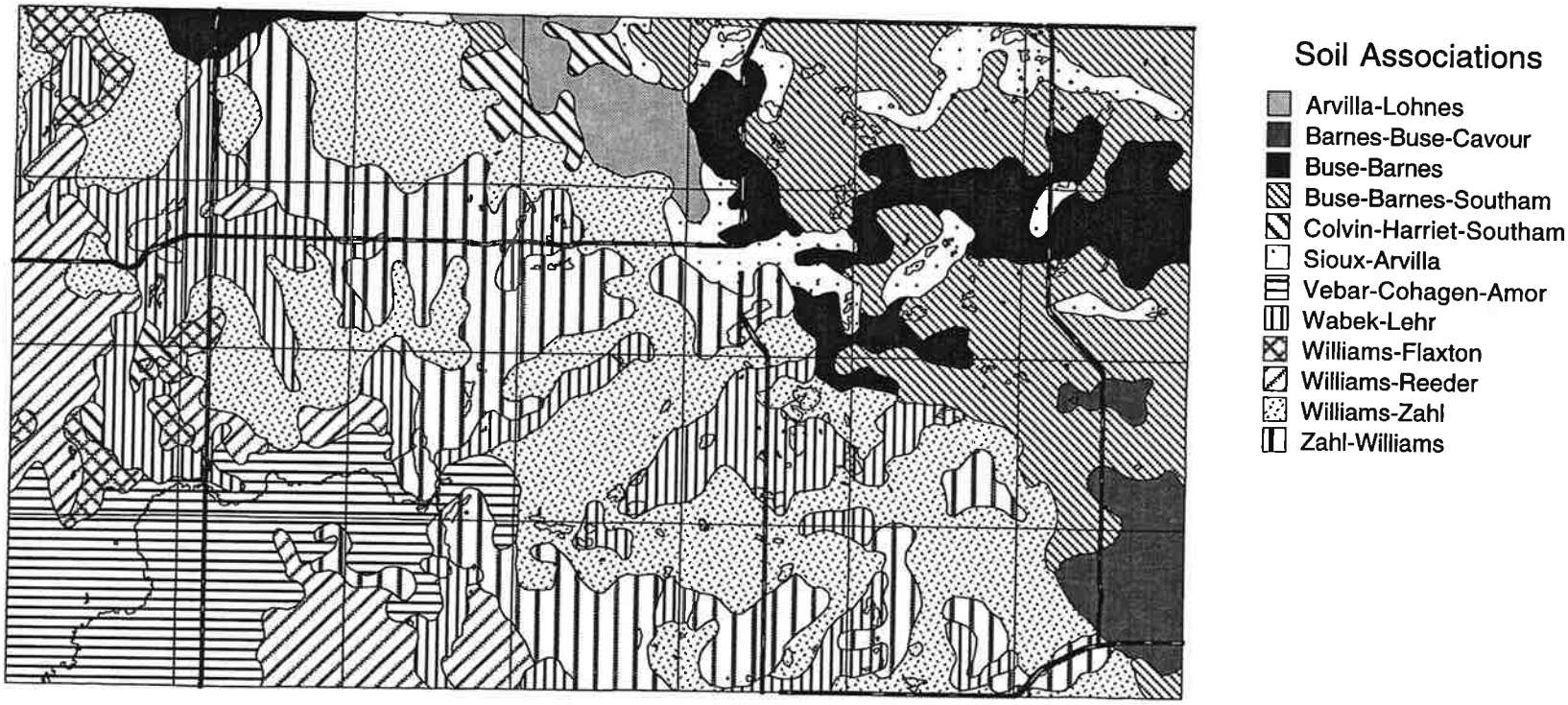

Figure Lo-1. Soil association map of Logan County ND. (From Logan County Soil Survey, USDA-SCS , Unpublished 1995).

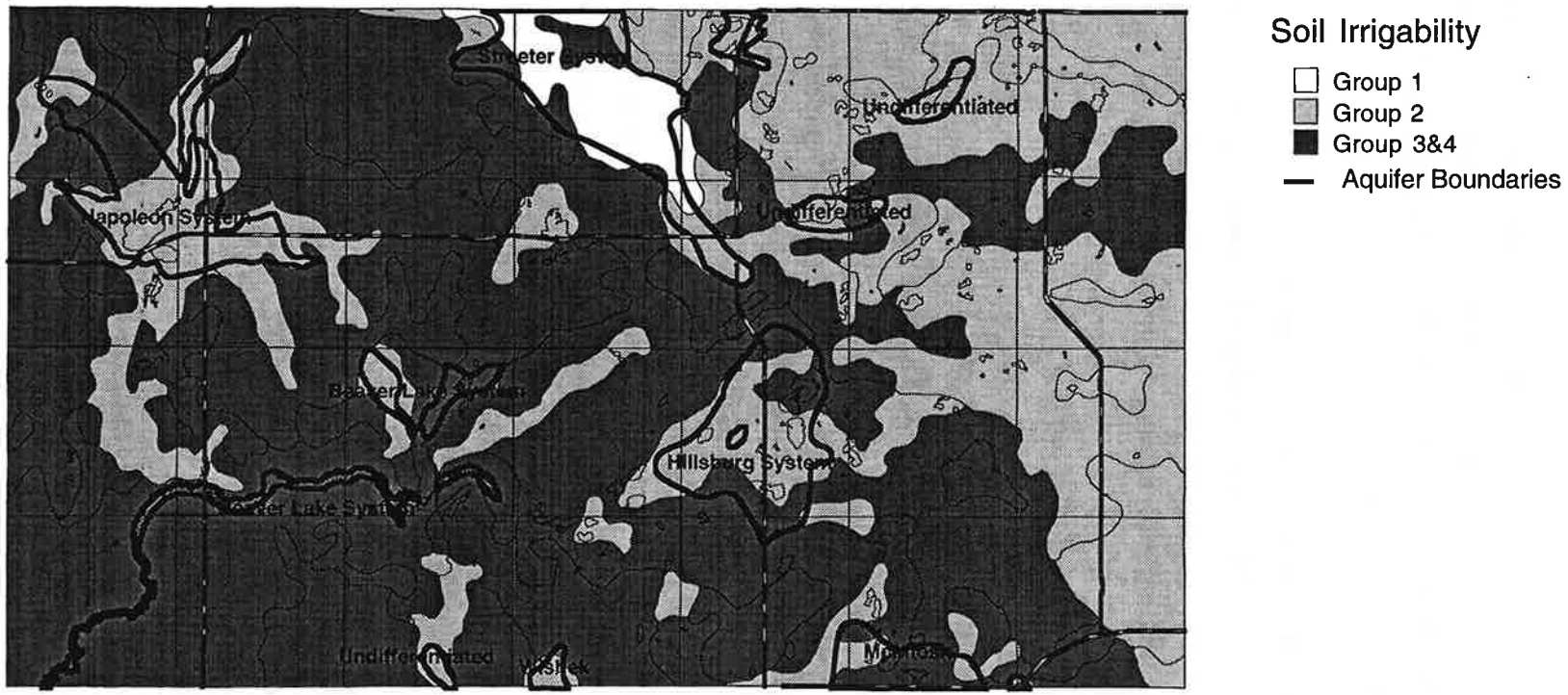

Figure Lo-2. Map of boundaries of the principal aquifers in Logan County, ND. (From Klausing, 1983).

12,801 acres. The final estimate of land available for irrigation development was further adjusted by a contingency factor of 1/2 to account for error, and for local preference in land use. **Based on soil suitability alone, about 6,500 acres** (6,401 acres) **of land overlying aquifers would be available for irrigation** (Table 1, Column 11).

Irrigable Land Overlying Aquifers Based on Water Supply Limitations

Ground-water resources in Logan County have good irrigation potential. In contrast to neighboring counties, water quality in most current wells is suitable for irrigation. Estimates of water available for potential irrigation are based on an estimated recharge of 0.3 inches per year for deeper confined aquifers in glacial till, 1.2 inch per year for shallow confined aquifers, 2.5 inches per year for aquifers that are partly confined, and partly unconfined, and 4 inches per year for unconfined aquifers. Irrigable acreage for each aquifer is then calculated by assuming an average of 12 inches per acre per year irrigation. The recharge coefficient is the estimated recharge divided by the 12-inch use estimate. Recharge coefficients calculated for 0.3, 1.2, 2.5, and 4 inches are 0.025, 0.1, 0.21, and 0.33, respectively.

While such simplified discrete numbers can be applied in some circumstances, many aquifers are comprised of highly complex systems of coarse deposits, varying from deeply buried to surficial positions. In such cases, an adjustment to the recharge coefficients is made based on an assessment of aquifer surface depths indicated by drill log information on the county-study maps. Resulting estimated recharge coefficients are shown on Table 1, column 6. Irrigation acreage based on sustainable water use is then calculated by multiplying the total area overlying the aquifer by the recharge coefficient.

Irrigation acreage based on sustainable water use, in turn, is adjusted by the water quality coefficient, which is the probability of obtaining water suitable for irrigation in a given well (Table 1, column 5). The most limiting parameter (of ECE, SAR, Boron) is used to adjust for water quality. The resulting irrigable acreage estimate based on recharge and water quality is in Table1, column 8. **About 13,500 acres are estimated to be potentially irrigable, based on estimates of available water suitable for irrigation.**

Total Potential Irrigation Development From Ground Water

Potential irrigation development is calculated using the most limiting of the above criteria for each aquifer. If the overlying soil is most limiting, soil criteria are used. If water supply is limiting, the water supply criterion is used. For Logan County, the land is more limiting than the amount of available land, for all aquifers. **The estimate of total potential irrigation development in Logan County is thus about 6,500 acres.** This amount is about 3 times the total current permitted

acreage. However, since development of all of the aquifers in this case is considered to be limited by available soil, it must be remembered that a 1/2 safety factor has been applied to the estimate, and that optimally, more land may be available. If all of the possibly irrigable land estimated (column 10) were considered, then as much as 12,000 acres (11,932 acres) might be available for irrigation development using the most limiting of the soil and water criteria for each aquifer.

Additional Discussion

For two aquifers having large apparent water availability, the Streeter aquifer and the Hillsburg aquifer systems, special considerations of the interaction of available soil and available water must be made. While the Streeter aquifer may have large amounts of water for potential use, there is currently a high concentration (about 15 quarter sections) of irrigation development near the center of the aquifer. Further irrigation development near the current use area will likely be limited because of possible interference with the supplies of current water users. In the southern part, the aquifer is thin, and will allow for only limited development. A rough estimate by the current managing hydrologist (Alan Wanek, personal communication, March 1995) would be about 3 quarter sections. In the northern part, land sufficiently distant from current development, and overlying ample available supplies of water is often limited by areas of high water table and sloughs. A rough estimate of up to 6 or 7 quarter sections might be available for irrigation. In sum, about 10 additional quarter sections might be developed. This, plus the current development, would total about 4,000 acres total development for the Streeter aquifer. This compares with 3,300 to 6,600 acres of available land, and an estimate of 5,914 acres based on water supply alone.

The Hillsburg aquifer is thin. This would limit the amount of water that could be pumped at any one location without interference between development tracts. The managing hydrologist has estimated that a development concentration of up to 1 quarter-section per section might be possible. Applying this limit to sections fully covered by the aquifer, would result in an estimate of about five sections, or about 2,560 acres of potential irrigation development from the Hillsburg aquifer. This compares with 1,354 to 2,708 acres of available land, and an estimate of 4,861 acres of available water for irrigation.

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT

Despite limitations in the pattern of development and in depth of the aquifers, independent estimates of potential irrigation development from the Hillsburg and Streeter aquifers did not differ greatly from computations based on least limiting factors (land or water) used in this report.

Approximately 6,500 acres of irrigation development appears to be feasible in Logan County. Additional development might be feasible under appropriate conditions, but would have to be implemented in carefully monitored stages.

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Potential Irrigation Development in McIntosh County, North Dakota

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT FOR MCINTOSH COUNTY

There are six aquifers in McIntosh County which provide water for potential irrigation development. About 36,000 acres overlying these aquifers have soils classified as irrigable or conditionally irrigable, have slopes of less than 3 %, are free from substantial surface and subsurface drainage requirements, and lie in parcels of sufficient size for irrigation. In this study, estimates of potentially irrigable land are based on total land classified as irrigable, multiplied by a contingency factor of 1/2 to account for potential error, and land owner preferences regarding development. The contingency factor is also intended to lend a conservative bias to this report. Application of the contingency factor results in an estimate of at least 18,000 acres of irrigable land overlying aquifers in McIntosh County.

Water quality for irrigation is variable. About 70% and 82% of water samples taken from the Dry Lake and Spring Creek aquifers, respectively, are of suitable quality for irrigation, based on the criteria of this study. For some other aquifers in McIntosh County, as much as 96 % of the water samples taken are suitable for irrigation. Estimates of long-term sustainable yield indicate that sufficient water for about 11,000 acres of irrigation is possible on a long-term basis. There is little potential for expanded irrigation using surface water in McIntosh County.

Potential irrigation development is estimated by summing the most limiting resource (irrigable land or water) for each aquifer. **Results indicate that development of at least 7,000 acres for irrigation should be feasible in McIntosh County.** Estimates of potential irrigation development in this report compare with a total of 300 acres currently permitted for irrigation in McIntosh County. This estimate is likely conservative, and it would not be implausible that some additional acres of irrigation might be developed in carefully monitored stages.

POTENTIAL IRRIGATION DEVELOPMENT IN McINTOSH COUNTY NORTH DAKOTA

The purpose of this report (chapter) is to provide an evaluation of land and water available for potential irrigation development in McIntosh County. Methods of assessment used in this report were designed to provide a conservative estimate. These methods were described in a previous introductory section. It is emphasized that the findings of this report are based on general information. They are preliminary in nature, and they should not be used for individual project siting without further local in-depth analysis. For the sake of continuity in computation, data in tables are provided to the nearest digit. However, this should not lead to the conclusion that this report can estimate acreage with such a high level of precision. **In the text of this report, the final summary estimates resulting from table computations are rounded to the nearest 500 acres.** These final rounded numbers reflect more appropriately the general character of these estimates.

Current Irrigation Development

In McIntosh County, the primary source of irrigation water is ground water. McIntosh County has very poorly defined external drainage, so that there are no major streams to provide a reliable surface water supply. While there are lakes and ephemeral potholes, these do not provide reliable supplies of water in most cases . There is currently little irrigation development in McIntosh County. In fact, there is only one irrigation permit for 302 acres. Total reported irrigation in McIntosh County from 1991 to 1993 varied narrowly from 15 acres in 1993, to a maximum of 17 acres in 1991 and 1992.

There is currently no approved irrigation using surface water. Because of the lack of major streams, and because of the complexities involved with lake hydrology and competing recreational and wildlife interests, surface waters in McIntosh County are excluded from consideration as sources. While some lake waters would likely be available for use, they would have to be considered as individual cases. Lakes should not be considered as a potential large source of water in McIntosh County.

POTENTIAL IRRIGATION DEVELOPMENT FROM GROUND WATER

Assessment of potential irrigable land in this report will not be limited to or based on actual current water permits, or on current actual irrigated acreage. Rather it will be based on evaluation of the water and soil resource. In McIntosh County six aquifers have been identified as potential sources for irrigation. These are listed on Table 1. There are two possible limiting factors affecting potential irrigation development using ground water. These are (1) irrigable land within

Table 1. Resources for potential irrigation development in McIntosh County, ND. EC is the electrical conductivity of water; SAR is the sodium adsorption ratio of water; and Boron is the concentration of boron in water. Potential irrigable acres based on water limitations (column 8) are calculated by multiplying the total acreage (column 7) by the recharge coefficient coefficient in column (6) as described in the text, and by adjusting for water quality (column 5). Land mapped in irrigable soils series, and having a slope of less than 3% (column 10) is calculated from land area mapped in irrigable associations overlying the aquifer (column 9), adjusted for the proportion of the association attributed to soils of irrigation suitable series, and by an adjustment factor (0.59) accounting for slopes greater than 3%. The final estimate of potential irrigation development is half of column 10. **Bold type** indicates most limiting estimate of potential irrigation, used in final estimates of potential irrigation development. (c) means aquifer is confined with less than 50 feet of overburdon. (c†) means that aquifer is deeply confined, having more than 50 feet of overburdon. (u) means that aquifer is unconfined. (c/u) means that aquifer is variably confined and unconfined.

(1) WATER SOURCE	(2) ECE %<1500 µS/cm	(3) SAR %< 6	(4) BORON %<2 mg/L	(5) WATER QUALITY COEFFICIENT	(6) RECHARGE COEFFICIENT	(7) AREA OVERLYING AQUIFER acres	(8) POTENTIAL IRRIGABLE ACRES-WATER LIMIT acres	(9) LAND MAPPED IN IRRIGABLE ASSOCIATIONS acres	(10) LAND MAPPED IN IRRIGABLE SOIL SERIES, SLOPE < 3% acres	(11) POTENTIAL IRRIGABLE SOIL OVERLYING AQUIFER acres
South Branch Beaver Creek c	90	90	100	0.90	0.1	6,355	**572**	4,913	1,478	739
Dry Lake c/u	70	70	100	0.7	0.21	8,601	1,264	3,040	717	**358**
McIntosh c†	90	100	100	0.90	0.05	13,920	**626**	13,964	1,510	755
Spring Creek -c†	85	82	100	0.82	0.05	67,584	**2,770**	64,552	25,821	12,910
Wishek u	100	96	100	0.96	0.33	14,259	4,517	6,705	1,582	**791**
Zeeland c/u	96	96	100	0.96	0.21	10,451	**2,106**	10,451	5,225	2,613
						121,170	11,855	103,625	36,383	18,191

* No water quality data were available. Used probability of most limiting case.

practical distance of the water source , and (2) available water of suitable quality in close proximity to irrigable land.

Total Irrigable Soils

There are approximately 635,825 acres in McIntosh County. According to a study conducted by North Dakota State University (NDSU) there are about 381,922 acres of irrigable and conditionally irrigable land in Griggs County (Omodt, written communication, 1982). About one third are classified as conditionally irrigable because of slope, drainage requirements, or slowness of internal drainage.

The classification used in this report is a much more restrictive subset of that used in the NDSU study. A soil association map (USDA-SCS, 1995, Unpublished) is provided on Figure Mci-1. Of this, there are about 52,280 acres of Group 1 (irrigable without limitations, slope less than 3 %) soils based on McIntosh County SCS soil survey tabulations. There are an additional 31,865 irrigable acres in the Group 2 category (irrigable with limitations). Usually the limitation is fineness of soil, which requires limited rates of water application. Soils requiring extensive surface or subsurface drainage are considered as non irrigable in this study. Thus, based on soil suitability alone, there are about 84,145 acres of potentially irrigable land. About 14% of all mapped soils are mapped as irrigable, with slopes of less than 3 %. Within soil series mapped irrigable, about half are of slope less than 3%. Estimates of federal and state lands are approximately 22,697 acres, and town lands are estimated at 3,842 acres. The total of government land is 26,539 acres. 14% of government land, or about 3,700 acres, is excluded from the estimate of total irrigable soil. **Thus, about 80,500 acres of potentially irrigable land is estimated for McIntosh County based on total irrigable land, without regard to proximity of water source.**

Irrigable Land Overlying McIntosh County Aquifers

McIntosh County has substantial ground water, in both confined and unconfined aquifers. About 121,170 acres overlie aquifers in McIntosh County (Table 1). Approximate aquifer boundaries are shown on Figure Mci-2. A map of soil suitability for irrigation is also shown on Figure Mci-2. About 18,191 acres of land located overlying aquifers are estimated to be irrigable. Potential irrigable soil overlying aquifers in McIntosh County is calculated by multiplying the area mapped to soils of irrigable associations by the percent of area within the association attributed to irrigation suitable soils series, and by an adjustment factor of 0.59 to account for slopes of more than 3%. The slope factor was computed as the ratio of the area of all irrigable soils in McIntosh County having slopes of less than 3%, divided by the total area of soils in irrigable series in the county. The final estimate of land available for irrigation development was further adjusted by a contingency factor of 1/2 to account for

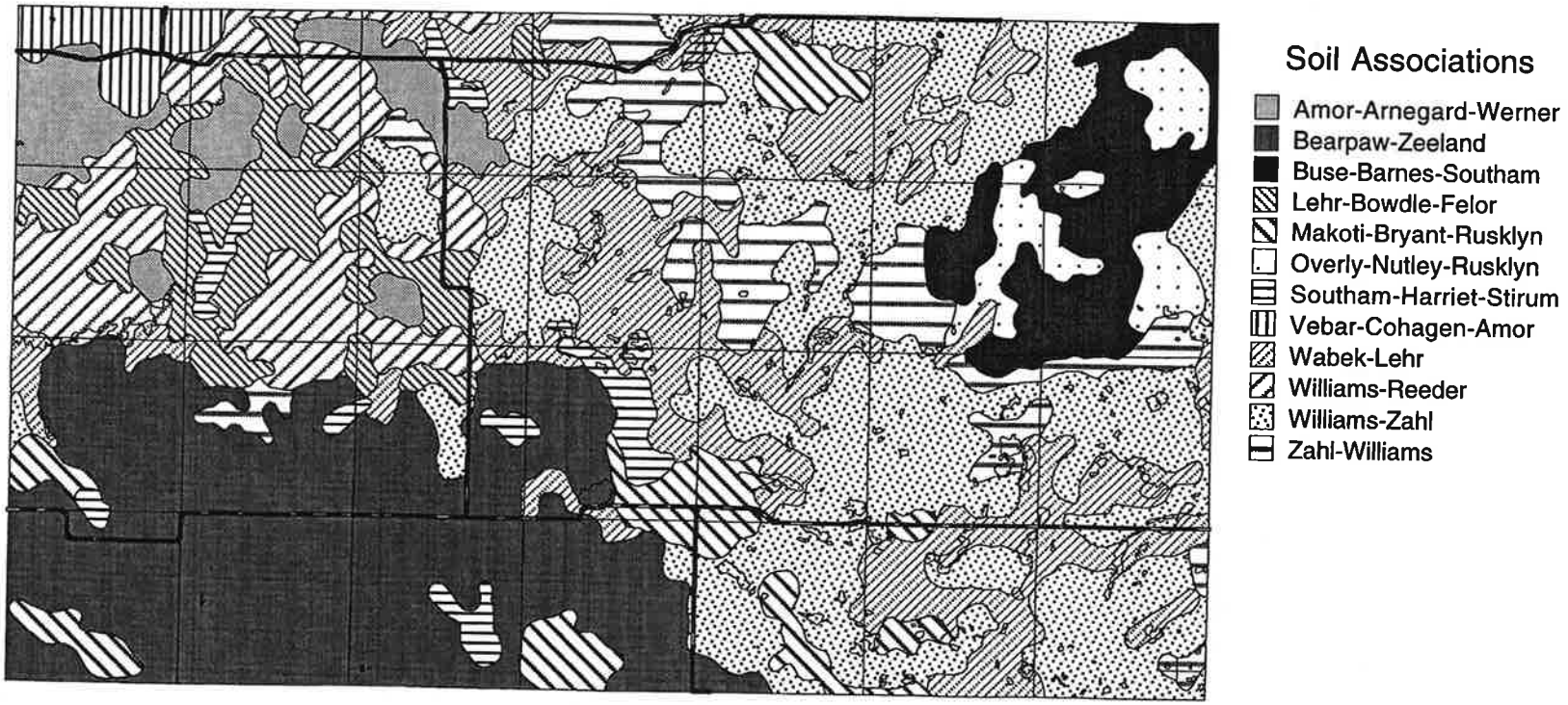

Figure Mci-1. Soil association map of McIntosh County ND. (From McIntosh County Soil Survey, USDA-SCS , unpublished 1995).

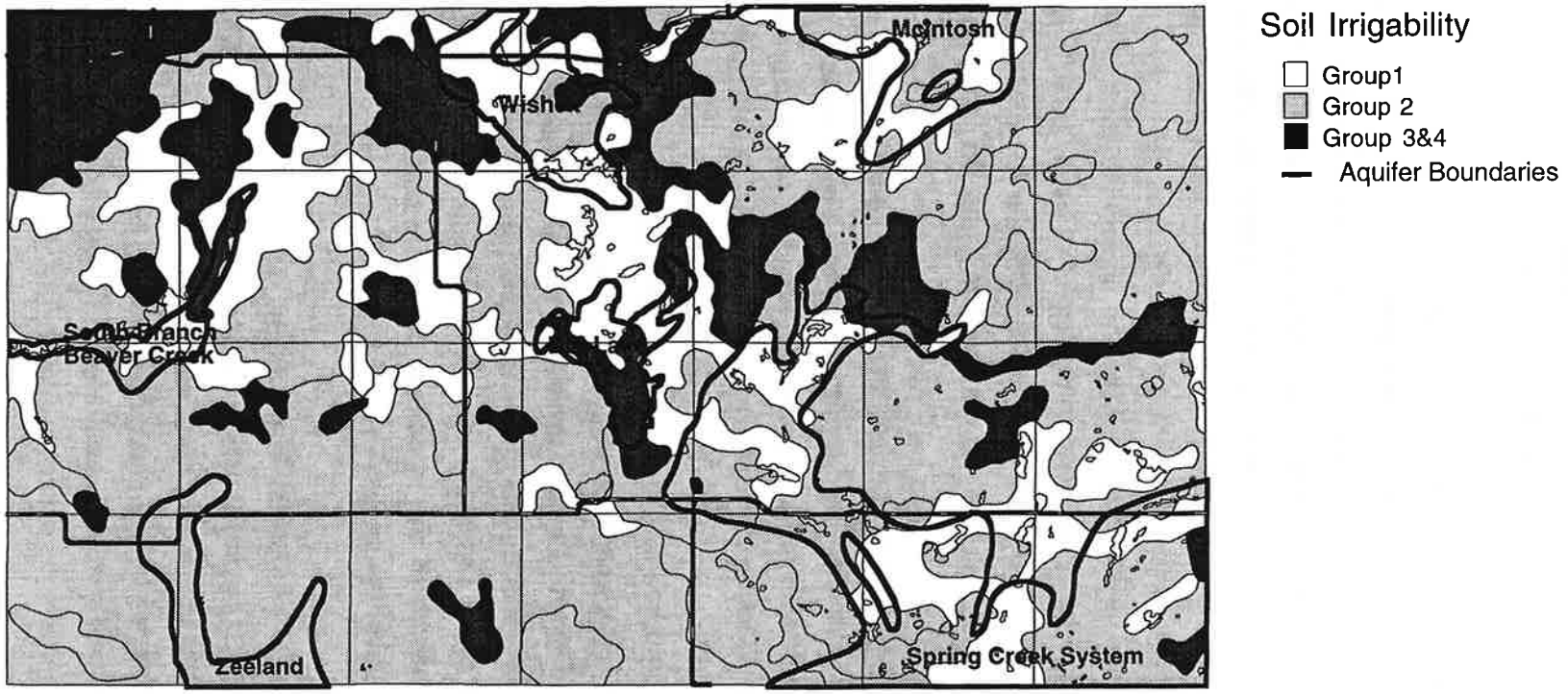

Figure Mci-2. Map of boundaries of the principal aquifers in McIntosh County, ND. (From Klausing, 1981).

error, and for local preference in land use. **Based on soil suitability alone, about 18,000 acres of land overlying aquifers would be available for irrigation** (Table 1, Column 11).

Irrigable Land Overlying Aquifers Based on Water Supply Limitations

Ground-water resources in McIntosh County have good quality for irrigation use. Between 70 and 100 % of the ground water from aquifers considered on Table 1 are of suitable quality for irrigation. Water quality is evaluated on the basis of suitable electrical conductivity (EC), sodium adsorption ratio (SAR), and Boron concentration (Table 1). Estimates of water available for potential irrigation are based on an estimated recharge of 0.3 inches per year for deeper confined aquifers in glacial till, 1.2 inch per year for shallow confined aquifers, 2.5 inches per year for aquifers that are partly confined, and partly unconfined, and 4 inches per year for unconfined aquifers. Irrigable acreage for each aquifer is then calculated by assuming an average of 12 inches per acre per year irrigation. The recharge coefficient is the estimated recharge divided by the 12-inch use estimate. Recharge coefficients calculated for 0.3, 1.2, 2.5, and 4 inches are 0.025, 0.1, 0.21, and 0.33, respectively.

While such simplified discrete numbers can be applied in some circumstances, many aquifers are comprised of highly complex systems of coarse deposits, varying from deeply buried to surficial positions. In such cases, an adjustment to the recharge coefficients is made based on an assessment of aquifer surfaces indicated by drill log information on the county-study maps. Resulting estimated recharge coefficients are shown on Table 1, column 6. Irrigation acreage based on sustainable water use is then calculated by multiplying the total area overlying the aquifer by the recharge coefficient.

Irrigation acreage based on sustainable water use, in turn, is adjusted by the water quality coefficient, which is the probability of obtaining water suitable for irrigation in a given well (Table 1, column 5). The most limiting parameter (of ECE, SAR, Boron) is used to adjust for water quality. The resulting irrigable acreage estimate based on recharge and water quality is in Table1, column 8. **About 12,000 acres would be estimated as potentially irrigable, based on estimates of available water of suitable quality for irrigation.**

Potential Irrigation Development From Ground Water in Griggs County

Potential irrigation development is calculated using the most limiting of the above criteria for each aquifer. If the overlying soil is most limiting, soil criteria are used. If water supply is limiting, the water supply criterion is used. For McIntosh County, both suitable soil and water supply are limiting. However, overall there is less available soil of suitable quality overlying aquifers than there is available water. By estimation criteria used in this report potential irrigation from the Beaver Creek aquifer, McIntosh, Spring Creek, and Zeeland aquifers are limited by available water supply, while potential

irrigation from the Dry Lake and Wishek aquifers appear to be limited by available soil suitable for irrigation. It must be remembered, however, that estimates of soil have been decreased by a factor of 1/2 to account for error and land use preference. More land than estimated may be available. The sum of most limited development estimates for each aquifer in McIntosh County is 7,233 acres. **The estimate of total potential irrigation development in McIntosh County is thus about 7,000 acres.** If soil suitability criteria were not adjusted by half, the final estimate would be closer to 8,000 acres. This compares with a current total of only 302 acres permitted for irrigation permits.

Additional Comments

The 7,000 to 8,000 acre estimate is likely conservative. There are indications of more coarse water-bearing deposits of limited size in McIntosh County, and further exploration will likely provide areas for potential development other than those already mapped and considered in this study. In addition, estimates for potential development are based on sustainable yield for an indefinite period. A reasonable and limited level of mining might be allowable where there is large aquifer storage, and such additional use could be applied for many years in some cases. This possibility would have to be evaluated on an individual aquifer basis. Finally, the reader is cautioned that the computation methods are general in nature, and on any given aquifer may be overly generous, or excessively limited. For example, in McIntosh County the area managing hydrologist has indicated that the estimates for the Zeeland aquifer might, in his opinion, be on the high end of the potential development range, while that of the Spring Creek aquifer system might be slightly pessimistic. Of course, this could only be confirmed by extensive investigation during the progress of development. To a certain degree, such variances in estimation should cancel in the overall evaluation of the county.

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT

Approximately 7,000 acres of potential irrigation, all from ground water, appears to be available for development in McIntosh County. Irrigation development of substantial additional acreage might be feasible under optimal conditions, but would likely have to be implemented in carefully monitored stages.

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Potential Irrigation Development in McLean County, North Dakota

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT FOR MCLEAN COUNTY

There are fifteen aquifers in McLean County which provide water for potential irrigation development. About 65,000 acres overlying these aquifers have soils classified as irrigable or conditionally irrigable, have slopes of less than 3 %, are free from substantial surface and subsurface drainage requirements, and lie in parcels of sufficient size for irrigation. In this study, estimates of potentially irrigable land are based on total land classified as irrigable, multiplied by a contingency factor of 1/2 to account for potential error, and land owner preferences regarding development. The contingency factor is also intended to lend a conservative bias to this report. Application of the contingency factor results in an estimate of at least 32,500 acres of irrigable land overlying aquifers in McLean County.

Water quality for irrigation is variable between aquifers. Between 0 and 73% of ground water sampled is of suitable quality for irrigation, based on the criteria of this study. Estimates of long-term sustainable yield indicate that sufficient water for about 17,500 acres of irrigation is possible on a long-term basis. After considering both land and water limitations, about 17,500 acres of irrigation would be potentially available for irrigation development using ground water.

Substantial surface water sources available for McLean County include the Missouri River, Lake Sakakawea, and Lake Audubon. There is sufficient irrigable soil within reasonable distance of the Missouri River to allow for approximately 22,784 acres of irrigation. Near Lake Sakakawea there are approximately 10,240 acres of land that might be suitable for irrigation development. There are also about 2,560 acres of irrigation that may be developed in McLean County, as part of a 4,000 acre water allocation from the McClusky Canal, authorized under the Garrison Diversion Unit Reformulation Act (GDU-RA) of 1986. Total potential irrigation from the Missouri River, Lake Sakakawea and the GDU-RA authorization is about 35,584 acres.

Additional potential irrigation development may be possible using water from Lake Audubon and from the McClusky Canal. Two possible additional projects include 13,700 acres currently being planned for irrigation development by the U.S. Bureau of Reclamation in the Turtle Lake Project. An additional 5,120 acres of irrigable land near lake Audubon, but not included in the Turtle Lake Project, may be suitable for irrigation development. Irrigation projects developed by federal agencies may be subject to crop limitations and farming practices required for consistency with federal crop subsidy programs.

If federal projects are excluded from the total, about 51,000 acres of land may be suitable for irrigation development in McLean County from combined ground-water and surface-water sources. If projects subject to federal restrictions are included, the total potentially irrigable land may be between 56,000 and 65,000 acres.

POTENTIAL IRRIGATION DEVELOPMENT IN MCLEAN COUNTY NORTH DAKOTA

The purpose of this report (chapter) is to provide an evaluation of land and water available for potential irrigation development in McLean County. Methods of assessment used in this report were designed to provide a conservative estimate. These methods were described in a previous introductory section. It is emphasized that the findings of this report are based on general information. They are preliminary in nature, and they should not be used for individual project planning without further local in-depth analysis. For the sake of continuity in computation, data on computation tables are provided to the nearest digit. However, this should not lead to the conclusion that this report can estimate acreage with such a high level of precision. **In the text of this report, the final summary estimates resulting from table computations are rounded to the nearest 500 acres.** These final rounded numbers reflect more appropriately the general character of these estimates.

Current Irrigation Development

In McLean County, there are currently a total of 14,894 acres allocated for irrigation in 79 permits. Of this, actual annual use between 1991 and 1992 varied from as little as 4,060 acres to as much as 6,993 acres (Table 1). Of this total, 9,853 acres have been approved for irrigation using ground water. Actual use from 1991 to 1993 varied from as little as 2,235 acres to as much as 4,867 acres. Surface-water permits total 5,790 acres. Actual use from 1991 through 1993 varied from 1,997 to 1,517 acres. Sub totals for different surface-water sources are shown on Table 1. Discrepancies between ground-water and surface-water parts, and the total are due to multiple use permits.

IRRIGATION DEVELOPMENT FROM GROUND WATER

Assessment of potential irrigable land in this report will not be limited to or based on actual current water permits, or on current actual irrigated acreage. Rather it will be based on evaluation of the water and soil resource. In McLean County fourteen aquifers have been identified as potential sources for irrigation. These are listed on Table 2. There are two possible limiting factors affecting potential irrigation development using ground water. These are (1) irrigable land within practical distance of the water source , and (2) available water of suitable quality in close proximity to irrigable land.

Table 1. Summary of current water permit allocations, and current water use in McLean County, ND. Total approved and reported use totals do not equal grand totals because some water permits are for multiple sources.

WATER SOURCE	PERMITED LAND (ACRES)	IRRIGATED ACRES IN 1991	IRRIGATED ACRES IN 1992	IRRIGATED ACRES IN 1993
Ground Water	9,853	4,867	4,598	2,235
Surface Water	5,790	2,517	2,712	1,997
Lake Sakakawea	1,409	345	585	679
Missouri Mainstem	2,833	1,670	1,598	923
Painted Woods Creek	533	23	61	46
Non Mainstem	1,207	480	468	588

Table 2. Resources for potential irrigation development in McLean County, ND. EC is the electrical conductivity of water; SAR is the sodium adsorption ratio of water; and Boron is the concentration of boron in water. Potential irrigable acres based on water limitations (column 8) are calculated by multiplying the total acreage (column 7) by the recharge coefficient coefficient in column (6) as described in the text, and by adjusting for water quality (column 5). Land mapped in irrigable soils series, and having a slope of less than 3% (column 10) is calculated from land area mapped in irrigable associations overlying the aquifer (column 9), adjusted for the proportion of the association attributed to soils of irrigation suitable series, and by an adjustment factor (0.53) accounting for slopes greater than 3%. The final estimate of potential irrigation development is half of column 10. **Bold type** indicates most limiting estimate of potential irrigation, used in final estimates of potential irrigation dev elopment. (c) indicates that aquifer is confined, (u) is unconfined, and (c/u) is variably confined and unconfined.

(1) WATER SOURCE	(2) ECE %<1500 µS/cm	(3) SAR %< 6	(4) BORON %<2 mg/L	(5) WATER QUALITY COEFFICIENT	(6) RECHARGE COEFFICIENT	(7) AREA OVERLYING AQUIFER acres	(8) POTENTIAL IRRIGABLE ACRES-WATER LIMIT acres	(9) LAND MAPPED IN IRRIGABLE ASSOCIATIONS acres	(10) LAND MAPPED IN IRRIGABLE SOIL SERIES, SLOPE < 3% acres	(11) POTENTIAL IRRIGABLE SOIL OVERLYING AQUIFER acres
Fort Mandan* - c	0	70	100	0	0.1	10,425	**0**	9,465	4,013	2,006
Garrison - c	23	0	95	0	0.025	1,849	**0**	1,849	441	220.5
Lost Lake/Painted Woods Lake - c/u	40/100*	53/100*	100/100*	0.4	0.17	23,020	**1,565**	21,580	6,862	3,431
Mercer* -u	100	100	100	.72	0.25	7,321	**1,317**	7,321	2,716	1,358
Lake Nettie - c/u / Horseshoe Valley - c/u / Strawbery Lake -c/u / Turtle Lake -c/u	72 / 60 / 82 / 93	72 / 50 / 84 / 100	96 / 100 / 100 / 100	0.72	0.17	105,536	**12,917**	101,696	37,729	18,864
Riverdale* -u	60	100	100	0.60	0.25	2,914	**437**	2,914	1,235	618
Snake Creek* - c	60	30	100	0.30	0.1	12,742	**383**	12,742	1,512	756
Weller Slough / Wolfe Creek* - c	25/60	78	100	0.25	0.025	9,632	**60**	9,632	3,063	1,531
White Shield - c	30	52	100	0.30	0.1	18,368	**551**	16,448	5,230	2,615
White Shield - c (reservation)	30	52	100	0.30	0.1	5,760	**173**	**5,760**	1,831	916
Total							17,403	189,407	64,632	32,316

* Sparse local data resulting in higher potential error of estimations.

Total Irrigable Soils

If water were not limiting there would be ample irrigable land in McLean County. There are approximately 1,270,443 acres in McLean County. A soil association map (USDA-SCS, 1979) is provided on Figure McL-1. Of this, there are about 97,780 acres of Group 1 (irrigable without limitations, slope less than 3 %) soils based on McLean County SCS soil survey tabulations. There are an additional 209,167 irrigable acres in the Group 2 category (irrigable with limitations). Usually the limitation is fineness of soil, which requires limited rates of water application. Soils requiring extensive surface or subsurface drainage are considered as non irrigable in this study. Thus, based on soil suitability alone, there are about 306,947 acres of potentially irrigable land.

Estimates of federal and state lands are approximately 47,048 acres, and town lands are estimated at 12,800. Coal lands are 8,372 acres. The total of excluded land is 68,220 acres. About 24% of all land is irrigable. Estimating that 24% of excluded land would be irrigable, 16,372 acres are subtracted from the estimate of total irrigable land, **giving an adjusted total of 260,574 irrigable acres**. Most of the land classed as irrigable in McLean County is conditionally irrigable. A map of soil Groups (irrigable, conditionally irrigable, and non irrigable) as defined for this study is provided on Figure McL-2. While much of McLean County is mapped to irrigable soil associations on Figure McL-2, a substantial portion of the soils mapped in irrigable associations have excessive slopes. Also, the relatively small amount of final estimated irrigable acreage is due to the fact that about 47% of land mapped in irrigable or conditionally irrigable classes has a slope greater than 3%, and could not be easily irrigated.

Estimates of Irrigable Soil Overlying Aquifers

The overall estimates of irrigable soils discussed above were taken from soil survey summary tables and were adjusted for slopes greater than 3%. Estimates of irrigation-suitable soil overlying aquifers were calculated by integrating the areas of mapped soil associations within mapped aquifer boundaries (Table 2, column 9). Area mapped to soil associations considered to be predominantly irrigable were adjusted by the percent of soil series within the association considered to be irrigable. In addition, irrigable series were adjusted to account for slopes greater than 3% using a factor of 0.53 (Table 1, column 10). Finally, a 1/2 contingency factor was applied to all estimates of irrigable soil area. Results in Table 2, column 11 indicated that in McLean County **about 32,500 acres of land overlying aquifers would be considered as potentially irrigable based on soil suitability alone.**

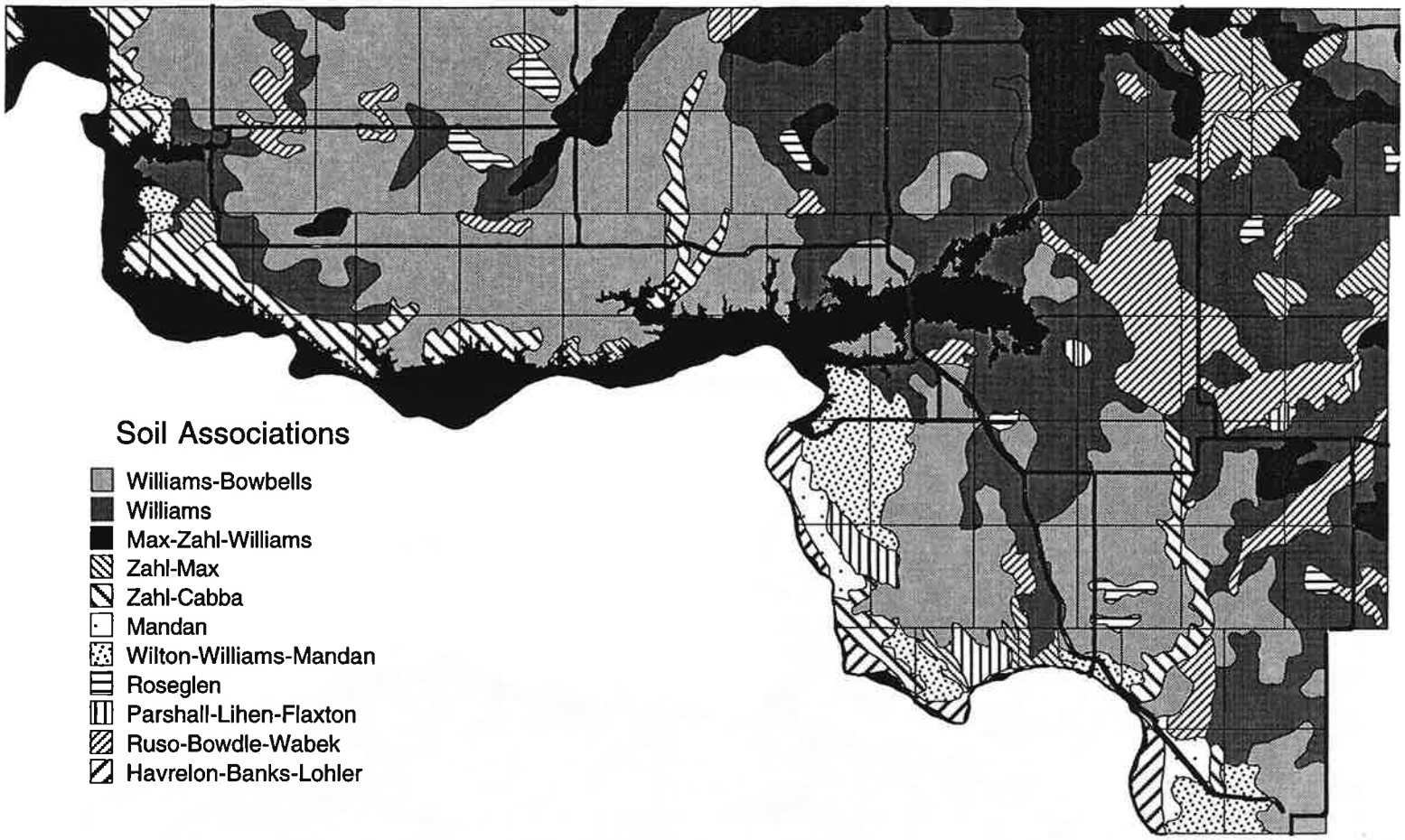

Figure McL-1. Soil association map of McLean County ND. (From McLean County Soil Survey, USDA-SCS , 1979).

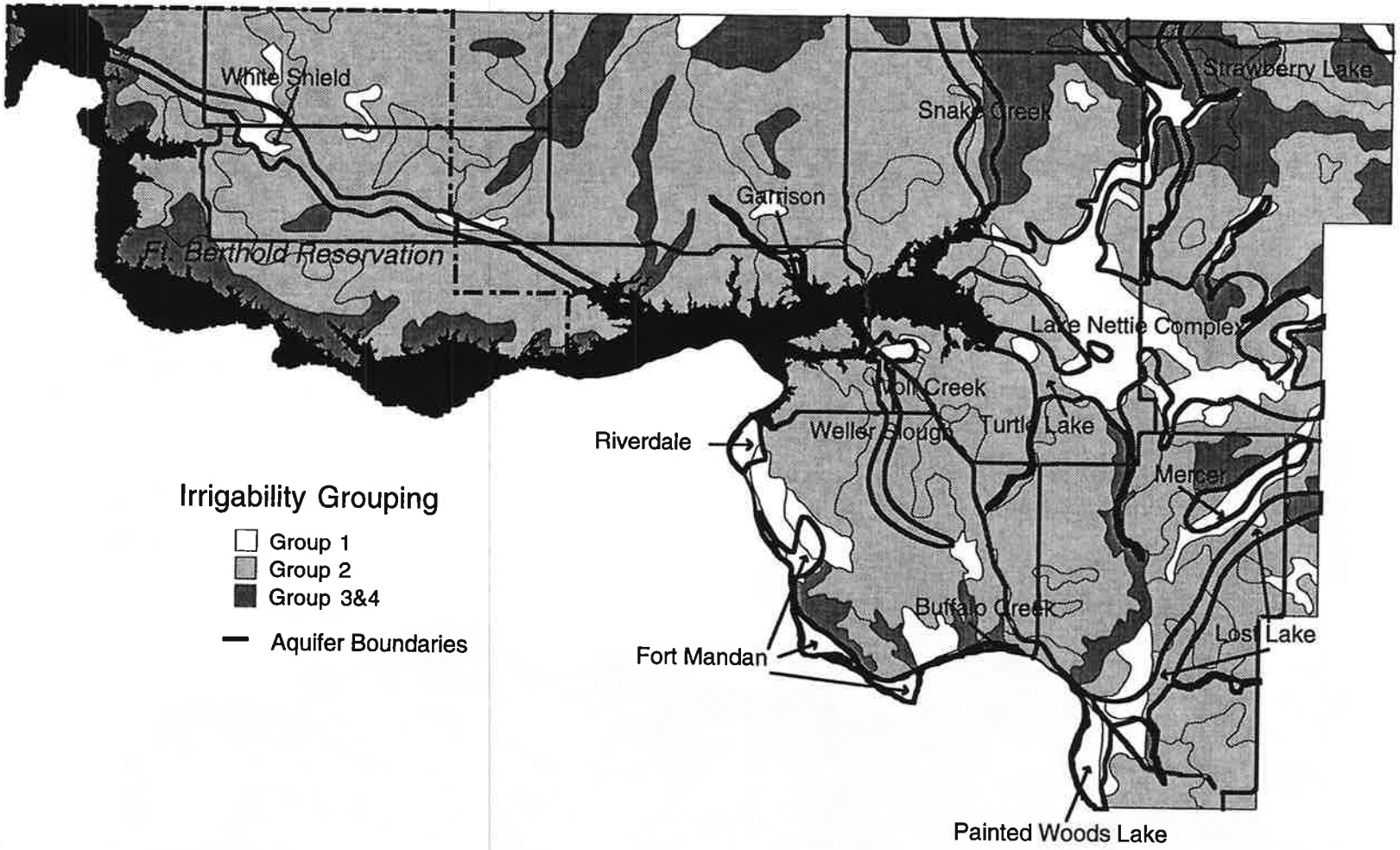

Figure McL-2. Map of boundaries of the principal aquifers in McLean County, ND. (From Klausing, 1974).

Irrigable Land Overlying Aquifers Based on Water Supply Limitations

Supplies of water suitable for irrigation are limited in most aquifers. Estimates of water available for potential irrigation development are based on an estimated recharge 0.3 inches per year for deeper confined aquifers in glacial till, 1.2 inch per year for shallow confined aquifers, 2 inches per year for aquifers that are partly confined, and partly unconfined, and 3 inches per year for unconfined aquifers. Irrigable acreage for each aquifer is then calculated by assuming an average of 12 inches per acre per year irrigation. The recharge coefficient is the estimated recharge divided by the 12-inch use estimate. Recharge coefficients calculated for 0.3, 1.2, 2.5, and 4 inches are 0.025, 0.1, 0.17, and 0.25, respectively. Slighty lower recharge estimates and sustained yield coefficients are used for McLean County, than for counties farther east because of somewhat lower (about 2 inches per year) average annual precipitation.

While such simplified discrete numbers can be applied in some circumstances, many aquifers are comprised of highly complex systems of coarse deposits, varying from deeply buried to surficial positions. Results must also consider variations in the overlying till, and the possibility of connection between stratified deposits. In McLean County most aquifers are combined unconfined and shallow confined units. Recharge coefficients selected for each of these aquifers are shown on Table 2, column 6.

Irrigation acreage based on sustainable water use is further adjusted by the water quality coefficient, which is the probability of obtaining water suitable for irrigation in a given well (Table 2, column 5). The most limiting parameter (of ECE, SAR, Boron) is used to adjust for water quality. The resulting irrigable acreage estimate based on recharge and water quality is in Table 2, column (8). **About 17,500 acres are estimated as potentially irrigable, based on estimates of available water of suitable quality for irrigation.**

Potential Irrigation Development from Ground Water in McLean County

The most limiting factor in Table 2 [water limiting (column 8); or soil limiting (column 11)] is used to estimate potential irrigation development from ground water in McLean County. Water is most limiting in every case. Based on Table 2, **about 17,500 acres are estimated as having potential for irrigation development in McLean County.** This compares with a current water-permit allocation of 9,853 acres, and actual current annual water use of close to 5,000 acres per year.

Additional Comments

Some of the aquifers considered for potential development have very low probabilities (25 to 40 % chance of obtaining good quality water for irrigation from a given well. Although development

from such supplies is certainly possible, there are additional problems of finding suitable water which add to the expense and difficulty of development. If low quality sources were excluded from analysis, and considerations were limited to higher quality sources, including the Mercer, Lake Nettie, Horseshoe Valley, Strawberry Lake, Turtle Lake, and Riverdale aquifers, then irrigation development potential would be estimated to be about 14,500 acres. This compares with a current ground-water permit allocation of 9,853 acres. In all likelihood, potential irrigation development from ground water in McLean County will be somewhere between 14,000 and 20,000 acres.

IRRIGATION DEVELOPMENT USING SURFACE WATER

Surface water sources in McLean County include the Missouri river (main stem, Lake Sakakawea, Lake Audubon), smaller land-locked lakes, and smaller tributaries of the Missouri River (Table 1). Of these the Missouri River represents a large potential water supply. In this study, only the Missouri River and Lakes Sakakawea and Audubon will be considered as possible sources of water for substantial irrigation development. Smaller streams may be ephemeral and provide unreliable supplies of water for dry periods. Small lakes are also excluded as potential water sources because of the complexities involved with lake hydrology and because of competing recreational and wildlife interests. While some lake waters would likely be available for use, they would have to be considered as individual cases. Lakes should not be considered as a potential large source of water in McLean county. Of waters in the Missouri River system considered for irrigation development, Lake Audubon and water from Lake Audubon conveyed by the McClusky canal must be treated as special cases because of Federal regulations and controls. For this reason, separate estimates will be made for potential surface-water irrigation from sources that must meet Federal Requirements under the Garrison Diversion Unit Reformulation Act of 1986.

Irrigation Development from Lake Audubon and the McClusky Canal

There are three potential water-development options that may be considered for waters from Lake Audubon and the McClusky. The first two options are: 1. the existing authorization of up to 4,000 acres of irrigation from the McClusky Canal, and 2. a plan for up to 13,700 acres of irrigation development under the Turtle Lake Irrigation and Wildlife Plan. The third option would consist of the use of Lake Audubon water for irrigation of land near Lake Audubon considered likely to be irrigable under the soil criteria of this report. The last option may be complicated or prohibited by differences in evaluation of soil suitability using our criteria and those of the U.S. Bureau of Reclamation. All of the federal water options are subject to limitations that may require prolonged periods of planning,

assessment, and project development. For this reason, they will be dealt with separately in the final summary of this report.

1. Under the Garrison Diversion Unit Reformulation Act of 1986, water for about 4,000 acres of irrigation should be available from the McClusky canal along its entire length, which includes portions in McLean, Burleigh, and Sheridan Counties. According to Jim Weigel of the Garrison Conservancy District, individuals interested in irrigation development should first contact the U. S. Bureau of Reclamation (USBR) area office in Bismarck, North Dakota. The USBR will conduct a survey to determine if soils in the proposed area are suitable for irrigation. If soils are suitable, a water permit will be required from the North Dakota State Water Commission, and a service contract outlining landowners' responsibilities and liabilities (with water fees) will be established with the USBR. Crops irrigated from the McClusky Canal will be subject to federal crop program limitations. Under current rules only non-program crops such as potatoes and vegetable crops or alfalfa could be irrigated, without paying a substantial water cost.

Assessment of soil suitability is performed by the USBR, using standards that may exclude some of the heavier soils used in our assessment. The 4,000 acres of irrigation allocation allowed in the Garrison Diversion Unit Reformulation Act of 1986 was based on a preliminary soil survey by U.S. Bureau of Reclamation planners. Maps of land considered irrigable in McLean County are available from the USBR. In 1988 the McClean County Water Resource District indicated that 2,560 acres were considered to be potentially irrigable from the McClusky Canal in McLean county . **The 2,560 acre estimate for potential irrigation in McLean County from the McClusky Canal will be used in this report.**

2. One large irrigation development proposed is described in the 13,700 acre Turtle-Lake Irrigation and Wildlife Area Conceptual Plan (USBR and others, 1993). This plan includes development of irrigation, wildlife, and recreational facilities in the Lake Nettie area, using Missouri River water from the McClusky canal and ground water. The proposed Turtle-Lake project uses land that lies predominantly over the Lake Nettie aquifer complex. About half of the proposed project acreage, 6,459 acres, has been estimated to be potentially irrigable using water from the Lake Nettie aquifer and nearby aquifers. Because of its preliminary status, the Turtle-Lake Irrigation and Wildlife Project estimates of irrigable land are not considered as a part of this assessment. However, the reader should be aware that **up to 13,700 additional irrigated acres over final estimates in this report, may be possible if the Turtle-Lake project is able to proceed.**

3. Conditions for potential irrigation development from a surface water source, explained in the Methods section for this report, include irrigable soil without large-scale drainage requirements within a short distance of the water source, and a total static lift of less than 260 feet required to supply water to project land. It is important that irrigation begin within a few miles of the water source, in order to optimize the cost effectiveness of the conveyance structures.

Much of the land in areas apportioned for irrigation in McLean County would be classified as conditionally irrigable. In this study, only soils not requiring large-scale subsoil or surface drainage are considered. Most common potentially irrigable soils are Falkirk and Williams series. The limiting condition is permeability, which decreases the amount of water that can be applied in a single irrigation-water application. One additional limitation can be the slope of the land. A substantial amount of land has a slope of greater than three percent. For this reason, soil maps were examined for each of the proposed tracts, and only quarter sections having predominant slopes of three percent or less were counted as having potential for irrigation.

There are two tracts of land within reasonable distance of access to Lake Audubon that might have substantial land for irrigation development, based on the soil suitability criteria of this study. Locations of these tracts are shown on Figure McL-3. Total potential irrigation from tracts 1 and 2 combined is about 5,120 acres. However, a portion of tract 2 overlaps the lands mapped for the Turtle Lake Project.

Tract 1. The first tract for potential irrigation development consists of about 5,120 acres located northwest of Lake Audubon within two townships T148 N, and R81/82 W. The total area, and total estimated potentially irrigable land within the tract are shown on Table 3. The nearest potential point of diversion is less than a mile from Lake Audubon.

Tract 2. The second tract is located due east of Lake Audubon. This tract is bounded on the northwest corner by tract 1, on the north by the Lake Nettie system, on the east by highway 41, on the south by the McClusky Canal, and on the west by the section line approximately 1 mile east of Lake Audubon. Total acreage, and estimated irrigable acres within the tract are shown on Table 3. The closest potential point of diversion is less than one mile from Lake Audubon. Another potential point of diversion is in the McClusky Canal. Large acreage development from Lake Audubon or from the McClusky Canal may be subject to the surplus crops penalty.

While these lands would be potentially irrigable using the criteria of this study which are based on state irrigation suitability classification, use of waters from Lake Audubon requires approval of the

Table 3. Amount of potentially irrigable land using Missouri River water. Missouri River water supply is treated as unlimited. Water quality is not limiting. A conservative adjustment factor of 1/2 is used. GDU-RA is the Garrison Diversion Unit Reformulation Act of 1986.

WATER SOURCE	Development Project or Tract	Estimated Irrigable Acres	Potential Development Tracts	Total Potential Development (acres)
Federal Requirements				
McClusky Canal, Future Projects *	Turtle Lake Project	13,700	Turtle Lake Project	13,700
Lake Audubon Tracts *	Tract 1	1,600		
	Tract 2	3,520	Tract 1 + Tract 2	5,120
Estimated Current Potential For Irrigation Development in McLean County From the McClusky Canal *	GDU-RA (McLean County Portion of 4,000 acres)	2,560		
Minimal Federal Requirements				
Lake Sakakawea	Tract 3	10,240		
Missouri River	Tract 4	11,520		
Missouri River	Tract 5	11,264	GDU-RA + Tract 3 + Tract 4 + Tract 5	35,584

* Development using waters of McClusky Canal must meet federal requirements.

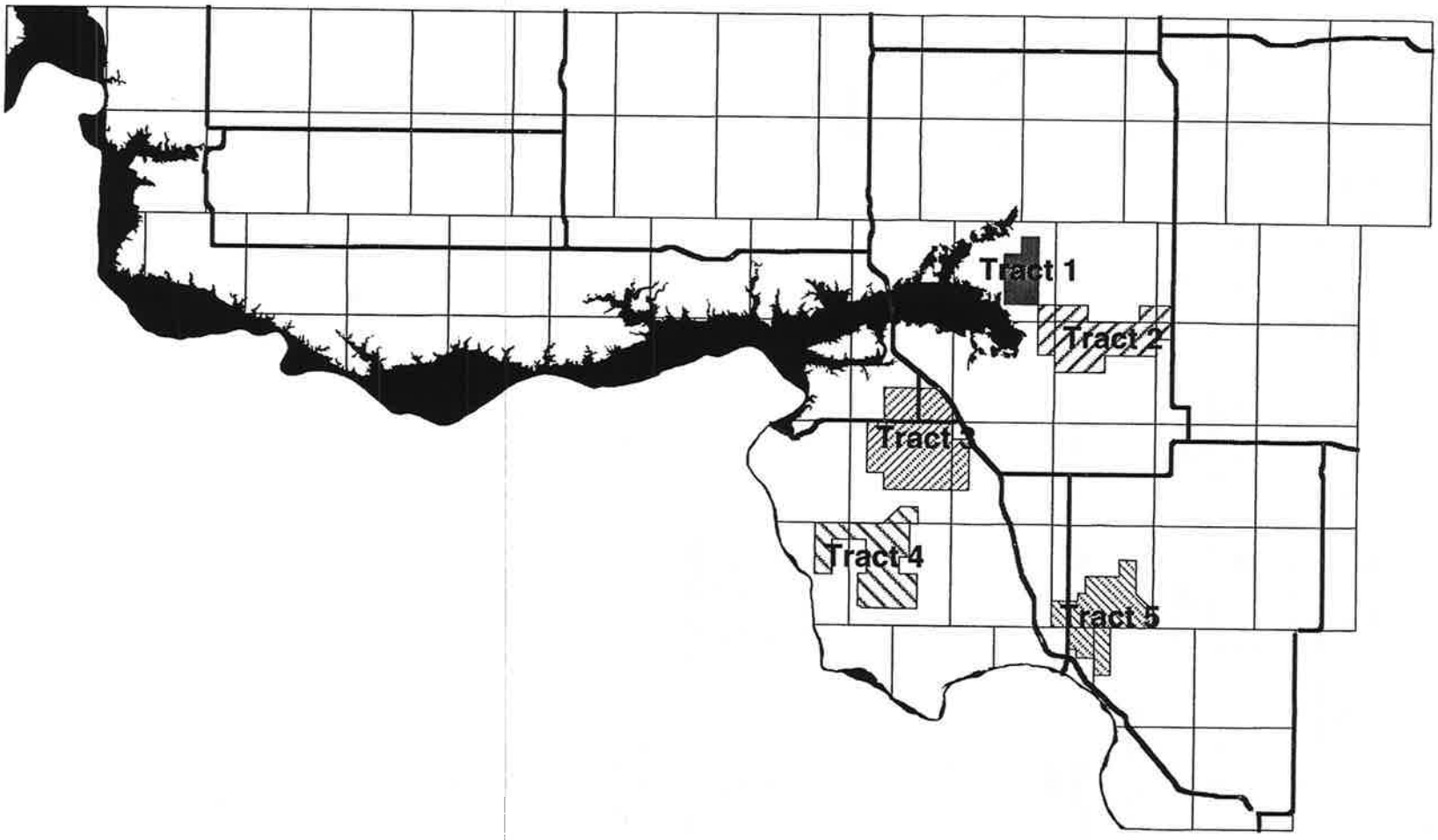

Figure McL-3. Map of locations of potential irrigation development tracts in McLean County using surface water.

USBR. Additional federal requirements might make development of these tracts more difficult. However, if the water-use situation is not limiting and highly competitive, there may be some flexibility in application of federal standards that would allow for development. Interest in development of potential tracts 1 and 2 shown on Figure McL-3 should begin with an inquiry to the USBR.

Irrigation Development Using Water From Lake Sakakawea and the Missouri River

Conditions for potential irrigation development from a surface water source have been explained in the Methods section in this report, and have also been discussed in the previous section on irrigation from Lake Audubon, under item (3). In McLean County, there are there are three additional tracts of land that may be considered as potential development areas for irrigation using water from Lake Sakakawea and the Missouri River. Locations of these tracts (tracts 3 through 5) are shown on Figure McL-3.

Tract 3. The third tract consists of about 19,200 acres located in the township of T146 N, R83 W. Boundaries are highway 83 on the east; the imaginary line through the north-south section line located 8 miles due west of highway 83 at Underwood in the west; the imaginary line passing through the east-west section line located one mile south of Coleharbor in the north; and the imaginary line passing through the section line located one mile south of Underwood in the south. There is a considerable amount (10,240 acres) of suitably level and potentially irrigable land in this tract. The closest potential point of water diversion for Lake Sakakawea is slightly more than a mile from the nearest irrigable land of the proposed development area.

Tract 4. The fourth tract consists of about 16,000 acres located southwest of tract 3 in T145/146 N and R 83/84 W. The northern boundary is the imaginary line passing westward through the east-west section line one mile south of Underwood. The southern boundary is the imaginary line passing eastward through the section line one mile north of Stanton. The approximate eastern boundary is one mile west of Weller Slough, and the approximate western boundary is one mile east of the Missouri River. There is a substantial amount (11,520 acres) of suitably level and conditionally irrigable land on this tract. The nearest potential point of water diversion is on the Missouri River in section 22, T 145, R 84 W, less than one mile from the potential development tract.

Tract 5. The fifth tract consists of about 14,720 acres located near Washburn and between highway 83 and Turtle Creek in T144, R81W. The southern boundary is at Washburn. The eastern and western boundaries are the R 81 west boundary lines. The northern boundary is the section boundary five miles south of highway 200. There is a substantial amount (11,264 acres) of

nearly level conditionally irrigable land on this tract. The nearest potential point of water diversion is on the Missouri River at Washburn, about a mile from the southern boundary of the potential development tract.

Surface Water Summary

Final estimates of potential irrigation using surface water in McLean County will be presented in two groups, based on federal requirements. The first group consists of potential irrigation with minimal federal limitations. This group includes tracts 3, 4, and 5 which are irrigated from the Missouri River and Lake Sakakawea (Table 3). It also includes a portion (2,560 acres) of water authorized (4,000 acres) for irrigation from the McClusky Canal under the Garrison Diversion Reformulation Act of 1986. The 2,560 acre figure is used, because only a portion of the McClusky Canal is in McClean County. 2,560 acres is the amount of irrigation water from the McClusky Canal requested in a water permit applied for by the McClean County Water Resource District . **The summary estimate of potential irrigation from surface water with minimal restrictions is about 35,500** (35,584) **acres.**

The second group consists of potential irrigation from water sources having federal requirements that may be substantial. **Two possible scenarios for this group include irrigation from Lake Audubon on tracts 1 and 2 described above, for about 5,120 acres; and the proposed 13,700 acre irrigation tract in the Turtle-Lake Irrigation and Wildlife Area plan.**

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT

If estimates are limited to water sources having minimal federal requirements, then total potential irrigation development in McClean County would be estimated at about 17,500 acres from ground-water sources, and about 35,500 acres from surface-water sources (including the Missouri River, Lake Sakakawea, and a limited amount from the McClusky Canal). Some of the tracts evaluated for possible surface-water irrigation development overlie aquifers. The amount of land (about 12,000 acres) in tracts 1 and 2 that overlie the Lake Nettie aquifer complex (as described in Table 2) is particularly significant. The ratio of the areas of potential surface-water irrigation overlying aquifers to total land surface areas of the aquifers are used to estimate the potential development areas using ground water that are duplicated in surface water development. The ratio derived is multiplied by the estimated adjusted water-limited irrigable acres on Table 2 to derive acreage of overlapping development. The total estimate of overlapping surface-water and ground-water development was

less than 2,000 acres. **After Adjusting for overlap of surface-water and ground-water development, the estimated total would be 51,000 acres** of potential irrigation development. If irrigation using waters having federal land and water resource assessment requirements is included, an additional 5,000 to 14,000 acres of irrigation might be possible. If made available, water from federally developed sources would result in an estimated total irrigation development potential of about 56,000 to 65,000 acres.

REFERENCES

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Potential Irrigation Development in Mercer County, North Dakota

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT FOR MERCER COUNTY

There are five aquifers in Mercer County which provide water for potential irrigation development. About 32,000 acres overlying these aquifers have soils classified as irrigable or conditionally irrigable, have slopes of less than 3 %, are free from substantial surface and subsurface drainage requirements, and lie in parcels of sufficient size for irrigation. In this study, estimates of potentially irrigable land are based on total land classified as irrigable, multiplied by a contingency factor of 1/2 to account for potential error, and land owner preferences regarding development. The contingency factor is also intended to lend a conservative bias to this report. Application of the contingency factor results in an estimate of at least 16,000 acres of irrigable land overlying aquifers in Mercer County.

Water quality for irrigation is variable between aquifers. Between 49 and 90% of ground water sampled is of suitable quality for irrigation, based on the criteria of this study. Estimates of long-term sustainable yield indicate that sufficient water for about 9,500 acres of irrigation is possible on a long-term basis. After considering both land and water limitations, about 8,000 acres of irrigation would be potentially available for irrigation development using ground water.

Substantial surface water sources available for irrigation use in Mercer County include the Missouri River and the Knife River. There is sufficient irrigable soil within reasonable distance of these two sources to allow for approximately 7,000 acres of irrigation.

Summing irrigation development estimates for both ground water and surface water, and subtracting to account for overlapping development (land counted for both ground-water and surface-water source development) results in a final estimate of **at least 14,000 acres for potential irrigation development in Mercer County.** Estimates of potential irrigation development in this report compare with a total of 9,178 acres currently permitted for irrigation in Mercer County.

POTENTIAL IRRIGATION DEVELOPMENT IN MERCER COUNTY NORTH DAKOTA

The purpose of this report (chapter) is to provide an evaluation of land and water available for potential irrigation development in Mercer County. Methods of assessment used in this report were designed to provide a conservative estimate. These methods were described in a previous introductory section. It is emphasized that the findings of this report are based on general information. They are preliminary in nature, and they should not be used for individual project planning without further local in-depth analysis. For the sake of continuity in computation, data on computation tables are provided to the nearest digit. However, this should not lead to the conclusion that this report can estimate acreage with such a high level of precision. **In the text of this report, the final summary estimates resulting from table computations are rounded to the nearest 5000 acres.** These final rounded numbers reflect more appropriately the general character of these estimates.

Current Irrigation Development

In Mercer County, there are currently 38 irrigation permits approved for 9,178 acres. Of this actual use from 1991 through 1993 varied from as little as 1690 acres to a maximum of 3882 acres. 2,645 acres were permitted for irrigation using ground water (Table 1). Actual irrigation using ground water varied from 929 to 1,124 acres from 1991 through 1993. Permits for irrigation of 7,415 acres using surface water have been approved. Actual use of surface water for irrigation from 1991 through 1993 has varied from 986 to 3068 acres. About half of the surface-water irrigation is from the Missouri River. The rest is from Lake Sakakawea, the Knife River, and other smaller tributaries of the Knife and Missouri Rivers.

IRRIGATION DEVELOPMENT FROM GROUND WATER

Assessment of potential irrigable land in this report will not be limited to or based on actual current water permits, or on current actual irrigated acreage. Rather it will be based on evaluation of the water and soil resource. In Mercer County six aquifers have been identified as potential sources for irrigation. These are listed on Table 2. There are two possible limiting factors affecting potential irrigation development using ground water. These are (1) irrigable land within practical distance of the water source , and (2) available water of suitable quality in close proximity to irrigable land.

Table 1. Summary of current water permit allocations, and current water use in Mercer County, ND.

WATER SOURCE	PERMITED LAND (ACRES)	IRRIGATED ACRES IN 1991	IRRIGATED ACRES IN 1992	IRRIGATED ACRES IN 1993
Total *	9,178	3381	3382	1690
Ground Water	2,645	1,116	1,124	929
Surface Water	7,415	2,577	3,068	986
Knife River	1,297	687	673	504
Lake Sakakawea	2,614	597	861	323
Missouri Mainstem	3,190	1,210	1,461	28
Non Mainstem	674	436	432	222

* Totals do not necessarily match the sum of ground water and surface water irrigation in the table because some permits are for both ground water and surface water irrigation.

Table 2. Resources for potential irrigation development in Mercer County, ND. EC is the electrical conductivity of water; SAR is the sodium adsorption ratio of water; and Boron is the concentration of boron in water. Potential irrigable acres based on water limitations (column 8) are calculated by multiplying the total acreage (column 7) by the recharge coefficient coefficient in column (6) as described in the text, and by adjusting for water quality (column 5). Land mapped in irrigable soils series, and having a slope of less than 3% (column 10) is calculated from land area mapped in irrigable associations overlying the aquifer (column 9), adjusted for the proportion of the association attributed to soils of irrigation suitable series, and by an adjustment factor (0.72) accounting for slopes greater than 3%. The final estimate of potential irrigation development is half of column 10. **Bold type** indicates most limiting estimate of potential irrigation, used in final estimates of potential irrigation dev elopment. (c) indicates confined aquifer, (u) is unconfined, and (c/u) indicates that aqufier is variably confined and unconfined.

(1) WATER SOURCE	(2) EC %<1500 µS/cm	(3) SAR %< 6	(4) BORON %<2 mg/L	(5) WATER QUALITY COEFFICIENT	(6) RECHARGE COEFFICIENT	(7) AREA OVERLYING AQUIFER acres	(8) POTENTIAL IRRIGABLE ACRES-WATER LIMIT acres	(9) LAND MAPPED IN IRRIGABLE ASSOCIATIONS acres	(10) LAND MAPPED IN IRRIGABLE SOIL SERIES, SLOPE < 3% acres	(11) POTENTIAL IRRIGABLE SOIL OVERLYING AQUIFER acres
Antelope Creek -c/u	90	90	100	0.9	0.17	9,350	**1,431**	6,150	2,877	1,438
Elm Creek-c/u	45	78	100	0.78	0.17	8,115	1,076	0	0	**0**
Goodman Creek -c/u	55	80	100	0.55	0.17	14,387	**1,345**	6,240	2,920	1,460
Knife River -c/u	49	73	100	0.49	0.17	43,897	**3,657**	42,617	19,944	9,972
Missouri River-c/u	83	73	100	0.73	0.17	11,622	**1,442**	9,382	4,187	2,093
Square Butte Creek *-c/u	49	73	100	0.73	0.17	4,070	**505**	3,360	1,644	822
Total						91,441	9,456	67,749	31,572	15,785

Total Irrigable Soils

A great deal of the land in Mercer County is non irrigable according to criteria used in this study. There are approximately 712,054 acres of land in Mercer County (649,770 acres after subtracting for surface water bodies). According to a study conducted by North Dakota State University (NDSU) there are about 258,721 acres of irrigable and conditionally irrigable land in Mercer County (Omodt, written communication, 1982). About 70 % is classified as conditionally irrigable because of slope, drainage requirements, or slowness of internal drainage.

The classification used in this report is a much more restrictive subset of that used in the NDSU study. A soil association map (USDA-SCS, 1978) is provided on Figure Me-1. All soils requiring extensive surface or internal drainage are excluded from consideration, and all soils having slopes of more than 3 % are also excluded. Using the criteria of this study, about 72,740 acres are classified as Group 1 (irrigable without limitations, slope less than 3 %) soils based on Mercer County SCS soil survey tabulations. There are an additional 36,469 irrigable acres in the Group 2 category (irrigable with limitations). About half (47%) of the soil classified in irrigable or conditionally irrigable series have slopes of more than 3% in Mercer County. Soils requiring extensive surface or subsurface drainage are considered as non irrigable in this study. Thus, based on soil suitability alone, there are about 109,199 acres of potentially irrigable land.

Federal, state, municipal, and coal lands are considered to be unavailable for irrigation development. Estimates of federal and state lands are approximately 19,282 acres, and town lands are estimated at 4,480. Coal lands are about 15,000 acres. The total of excluded land is 38,762 acres. If the proportion of excluded lands that are irrigable is similar to the rest of the county (17%) then about 6,589 acres of the excluded land would be subtracted from the irrigable class. Adjusted for government and coal land, **about 102,500 acres** (102,609 acres) **are considered to be potentially irrigable in Mercer County.** A map of soil Groups (irrigable, conditionally irrigable, and non irrigable) as defined for this study is provided on Figure Me-2. Estimates of total irrigable soils in Mercer County by North Dakota State University (NDSU) as provided by Omodt (982, written communication), are more than double this estimate (258,000 acres). However, the criteria used in this study consist of a much more restrictive subset of the criteria used in the NDSU study. All soils requiring surface, or subsurface drainage are excluded, and all soils having slopes greater than 3% are excluded.

Estimates of Irrigable Soil Overlying Aquifers

The overall estimates of irrigable soils discussed above were taken from soil survey summary tables and were adjusted for slopes greater than 3%. Estimates of irrigation-suitable soil overlying aquifers were calculated by integrating the areas of mapped soil associations within mapped aquifer

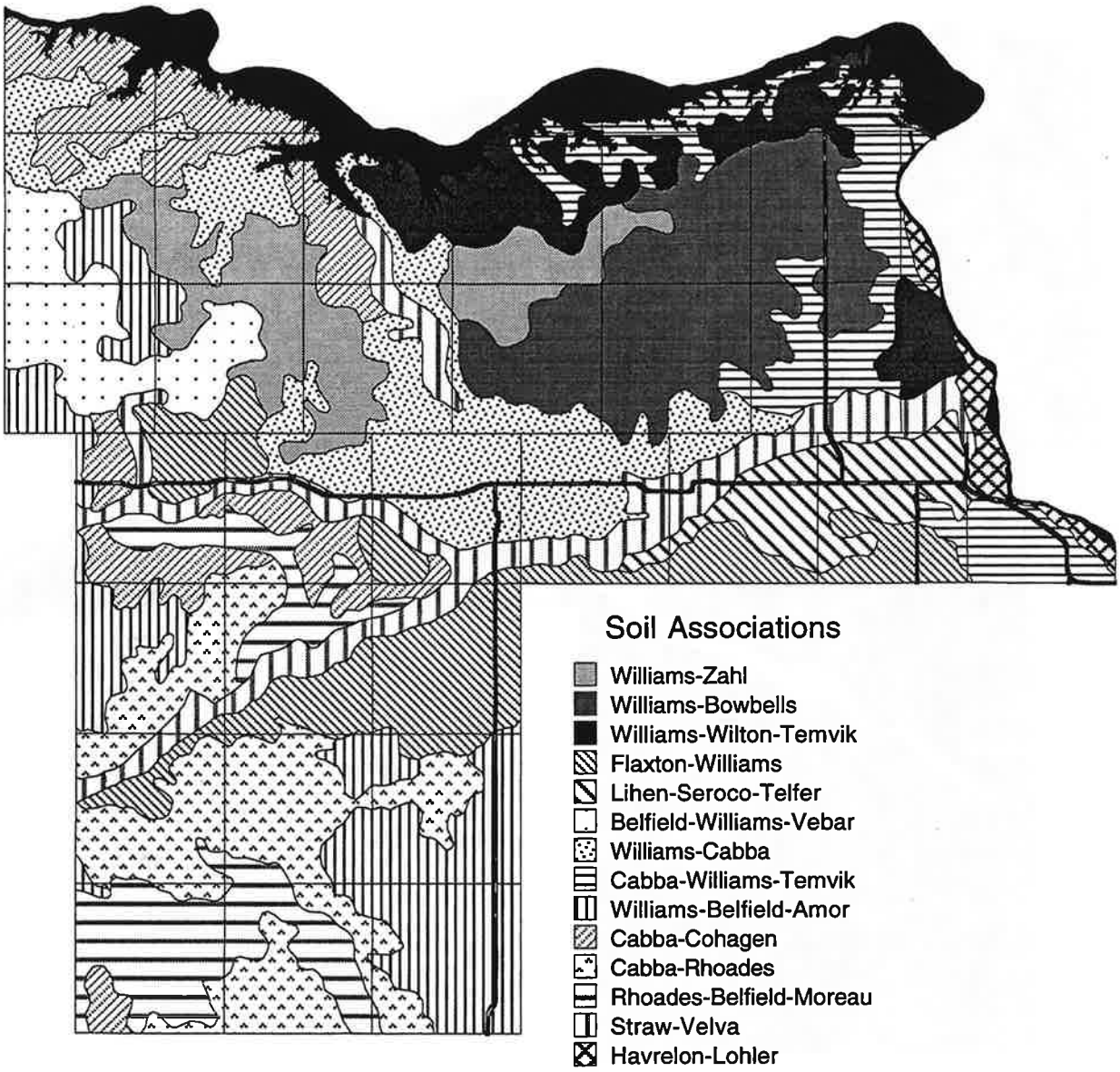

Figure Me-1. Soil association map of Mercer County ND. (From Mercer County Soil Survey, USDA-SCS , 1978).

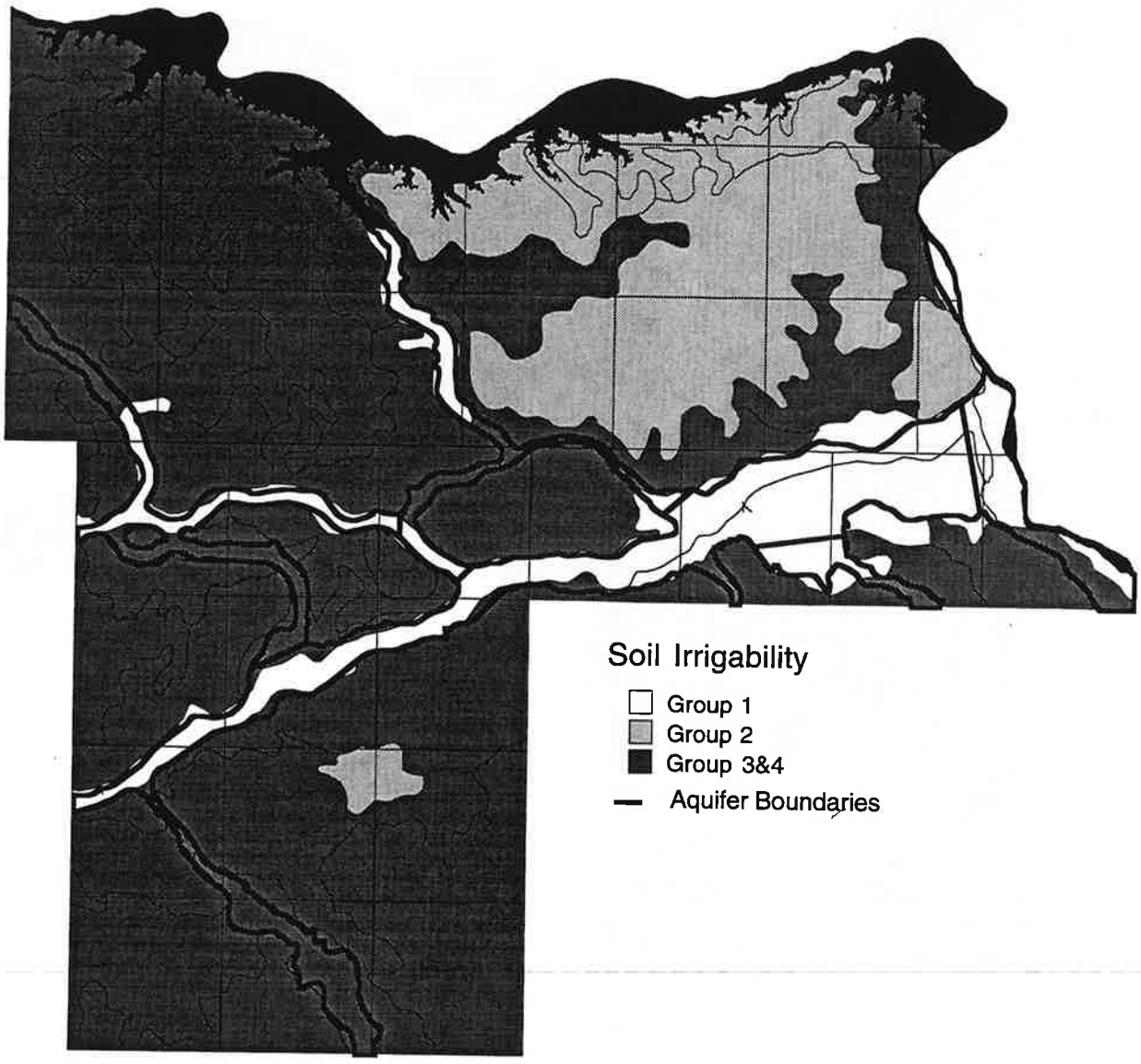

Figure Me-2. Map of boundaries of the principal aquifers in Mercer County, ND. (From Croft, 1973).

boundaries (Table 2, column 9). Soil association area was further adjusted by the fraction of the association attributed to irrigable soil series within the association. Soil series do not account for the fraction of the soil series of excessive slope, so a further adjustment was made for the series fraction having slope of 3% or less. The Mercer County soil summary table data indicated that about 72 % of soils considered irrigable by association alone had acceptable (less than 3 %) slopes (Table 2, column 10, adjusted for slope and series). Finally, a contingency factor of 1/2 was a applied to account for error, interaction of soil and water suitability, and land use preference. Results in Table 2, column 11, indicated that **about 16,000 acres** (15,785 acres) **of land overlying aquifers would be considered as potentially irrigable based on soil suitability alone.**

Irrigable Land Overlying Aquifers Based on Water Supply Limitations

Supplies of water suitable for irrigation are limited in most aquifers. Estimates of water available for potential irrigation development are based on an estimated recharge 0.3 inches per year for deeper confined aquifers in glacial till, 1.2 inch per year for shallow confined aquifers, 2 inches per year for aquifers that are partly confined, and partly unconfined, and 3 inches per year for unconfined aquifers. Irrigable acreage for each aquifer is then calculated by assuming an average of 12 inches per acre per year irrigation. The recharge coefficient is the estimated recharge divided by the 12-inch use estimate. Recharge coefficients calculated for 0.3, 1.2, 2.5, and 4 inches are 0.025, 0.1, 0.17, and 0.25, respectively. Slightly lower recharge estimates and sustained yield coefficients are used for Mercer County, than for counties farther east because of somewhat lower (about 2 inches per year) average annual precipitation.

Almost all of the aquifers in Mercer County are partially confined. Moreover, many underlie streams that would also enhance recharge. After considering these combined factors, an estimated recharge of about 2 inches per year was assigned to the partially unconfined aquifers. Potential irrigated acreage was computed by multiplying the total area overlying each unconfined aquifer (Table 2, column 7) by 0.17 (2 inches divided by 12 inches average annual irrigation, Table 2, column 6).

A further limitation on water supply for irrigation is water quality. Probability plots for electrical conductivity (ECE), sodium adsorption ratio (SAR), and boron were graphed for all water samples in the North Dakota State Water Commission data base, for each aquifer (Table 2, columns 2, 3, and 4). Estimated sustainable yield was multiplied by the most limiting fraction of suitable water based on these three chemical parameters (Table 2, column 5). Aquifers having inadequate data were either grouped with other nearby aquifers, or were adjusted using fractions obtained from probability plots for data from all aquifers in Mercer County. Results of these computations are shown on Table 2, column 8. **A total of about 9,500 acres** (9,456 acres) **was estimated as potentially irrigable using ground water, based on water supply limitations in Mercer County.**

Potential Irrigation Development from Ground Water in Mercer County

The most limiting factor in Table 2 [water limiting (column 8); or soil limiting (column 11)] is used to estimate potential irrigation development from ground water in Mercer County. For all but one aquifer (Elm Creek), which is overlain by non irrigable soils, sustainable yield is the limit. However, there is a large disparity between estimated sustainable yield and suitable land on only one aquifer, the Knife River aquifer. In all other cases, soil and water limitations are quite close. Based on Table 2, **about 8,000 acres** (8,380 acres) **are estimated as having potential for irrigation development in Mercer County.** This compares with 2,645 acres currently permitted for irrigation from ground water, and a current actual use of about 1,000 acres per year (Table 1).

Additional Comments

Aquifers in Mercer County offer a reasonably good chance of finding water of suitable quality. They are also deep enough to provide for good pumpability in many areas. Estimates for potential development are based on sustainable yield for an indefinite period. In some cases recharge from overlying streams may result in larger recharge during spring. Also, a reasonable and limited level of mining might be allowable where there is large aquifer storage, and such additional use could be applied for many years in some cases. This possibility would have to be evaluated on an individual aquifer basis.

Finally, the reader is cautioned that the computation methods are general in nature, and on any given aquifer may be overly generous, or excessively limited. To a certain degree, such variances in estimation should cancel in the overall evaluation of the county. Actual irrigation potential for a given aquifer could only be determined through detailed local investigation, and through the ongoing process of assessment which occurs during the implementation of gradual irrigation development.

IRRIGATION DEVELOPMENT USING SURFACE WATER

Surface water sources in Mercer County include the Missouri river (main stem and Lake Sakakawea), the Knife River, and smaller land-locked lakes, and smaller tributaries of the Missouri River and Knife River(Table 1). Of these the Missouri River represents a large potential water supply. In Mercer County there are currently 7,415 acres permitted for irrigation from surface water sources. Actual irrigation from 1991 through 1993 was between 1,000 and 3,000 acres. There are currently 1,297 acres approved for irrigation from the Knife River. Actual current irrigation from the Knife River is about 500 to 700 acres (Table 1).

In Mercer County, there appears to be only one major tract of land with substantial surface-water irrigation development potential. This tract is the Knife River valley. While there is considerable land mapped as conditionally irrigable bordering on Lake Sakakawea, much of this land has appreciable slope, and there are also many intervening small streams and coulees that would make development difficult. The proposed Knife River tract is shown on Figure Me-3. The eastern boundary of the proposed tract is the first north-south section line west of the Missouri River at Stanton. The southern boundary is Highway 200 and Alternate Highway 200. The western boundary is the imaginary line through the north-south section line 2 miles east of Hazen. The northern boundary is approximately one mile north of Knife River (east of Highway 200 north to Pick City) and approximately one mile south of the Knife River west of Highway 200 (north to Pick City). Total area is approximately 15,436 acres. Adjusting for a contingency factor of 1/2, about **7,000 acres of potential irrigation is estimated for the Knife River Valley, using surface water.**

There are two potential surface-water sources for development in the Knife River valley. The first potential water supply is the Missouri River. There appear to be ample areas for potential diversion from the Missouri River at the mouth of the Knife River. The second source of water is the Knife River itself. There are currently 1,297 acres of approved irrigation using water from the Knife River. A log probability plot of average August flows for the Knife River from 1963 to 1990 indicated that in 9 out of 10 years, August flows would equal or exceed 15 cfs. This totals about 900 acre feet for the month of August. Considering that August irrigation is usually about 30 percent of total annual irrigation, the Knife river at Hazen should support annual irrigation of about 3,000 acres in nine years out of ten. Allowing for about five hundred acre-feet of flow in a dry year, the **Knife river might support as much as double the current allocation, or about 2,500 acre feet.**

The same potential development tract may be irrigated by Knife River water, Missouri River water, and also from the portion of the Knife River aquifer underlying the tract. About 27 percent of the entire mapped Knife River aquifer underlies the potential surface water development tract. Applying this percent to total potential development from the Knife River aquifer based on water limitations (column (7), Table 2), about 900 acre feet of ground water might be used in the proposed surface water development tract. **Thus, there is a potential irrigation development tract in the Knife River Valley between Stanton and Hazen, consisting of about 7,000 acres, that might be irrigated by the combined waters of the Knife River aquifer (up to 900 acres), the Knife River (up to 2,500 acres), and the Missouri River (potentially unlimited supply).**

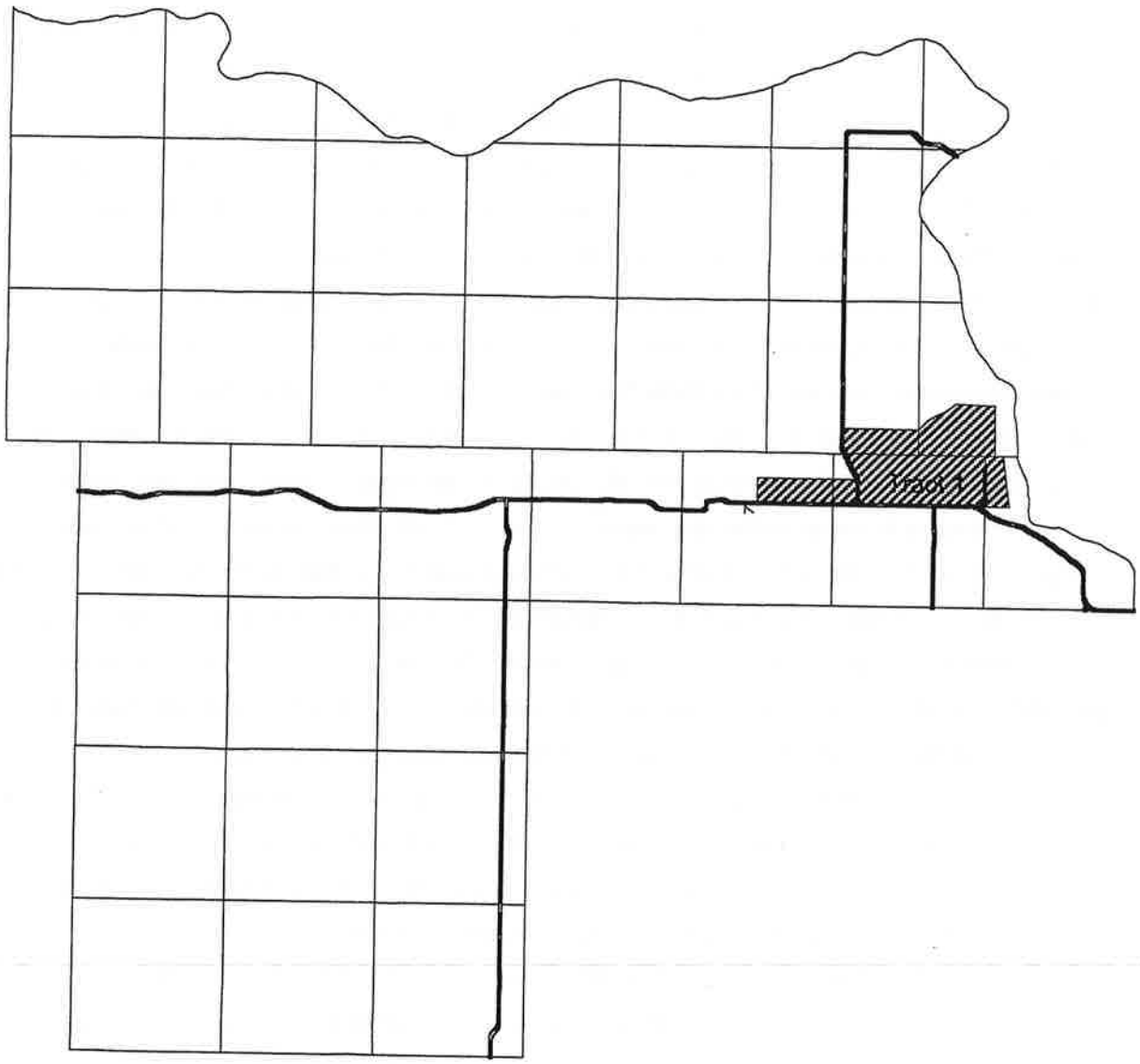

Figure Me-3. Map of land that is potentially irrigable using water from the Missouri River.

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT

Combined overlap of surface water development and water supplies from the Knife River aquifer and the Missouri River aquifer totals about 1,000 acres. This leaves a total of about 7,380 acres potentially irrigable from aquifers outside of the potential surface water irrigation tract. About 7,000 acres appears to have potential for irrigation development in the Knife River valley between Stanley and Hazen, using combined Missouri River, Knife River, Missouri River aquifer, and Knife River aquifer water supplies. **Total potential for irrigation development in Mercer County is approximately 14,000 acres.**

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Omodt, Hollis W. 1982. Irrigability of soil mapping units by county. Written Communication to Larry Knudtson, January 4, 1992.

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Potential Irrigation Development in Oliver County, North Dakota

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT FOR OLIVER COUNTY

There are two aquifers in Oliver County which provide water for potential irrigation development. About 12,500 acres overlying these aquifers have soils classified as irrigable or conditionally irrigable, have slopes of less than 3 %, are free from substantial surface and subsurface drainage requirements, and lie in parcels of sufficient size for irrigation. In this study, estimates of potentially irrigable land are based on total land classified as irrigable, multiplied by a contingency factor of 1/2 to account for potential error, and land owner preferences regarding development. The contingency factor is also intended to lend a conservative bias to this report. Application of the contingency factor results in an estimate of at least 6,000 acres of irrigable land overlying aquifers in Oliver County.

Water quality for irrigation is variable between aquifers. Between 49 and 73% of ground water sampled is of suitable quality for irrigation, based on the criteria of this study. Estimates of long-term sustainable yield indicate that sufficient water for about 3,500 acres of irrigation is possible on a long-term basis. After considering both land and water limitations, about 3,500 acres of irrigation would be potentially available for irrigation development using ground water.

The only substantial surface water source available for Oliver County is the Missouri River. There is sufficient irrigable soil within reasonable distance of the Missouri River to allow for approximately 6,500 acres of irrigation. Under optimal conditions more might be irrigated.

Summing irrigation development estimates for both ground water and surface water, and subtracting to account for overlapping development (land counted for both ground-water and surface-water source development) results in a final estimate of **at least 8,500 acres for potential irrigation development in Oliver County.** Estimates of potential irrigation development in this report compare with a total of 7,264 acres currently permitted for irrigation in Oliver County.

POTENTIAL IRRIGATION DEVELOPMENT IN OLIVER COUNTY NORTH DAKOTA

The purpose of this report (chapter) is to provide an evaluation of land and water available for potential irrigation development in Oliver County. Methods of assessment used in this report were designed to provide a conservative estimate. These methods were described in a previous introductory section. It is emphasized that the findings of this report are based on general information. They are preliminary, and they should not be used for individual project planning without further local in-depth analysis. For the sake of continuity in computation, data on computation tables are provided to the nearest digit. However, this should not lead to the conclusion that this report can estimate acreage with such a high level of precision. **In the text of this report, the final summary estimates resulting from table computations are rounded to the nearest 500 acres.** These final rounded numbers reflect more appropriately the general character of these estimates.

Current Irrigation Water Use

In Oliver County, there are currently 37 irrigation permits for a total of 7,264 acres. Annual use averages less than half of the approved acreage. Between 1991 and 1993 largest irrigated acreage was 3,006 in 1992. Least irrigation (994 acres) occurred in 1993, which was an extremely wet year. In most years it is likely that nearly 3,000 acres are irrigated.

IRRIGATION DEVELOPMENT FROM GROUND WATER

In Oliver County, there are currently 764 acres permitted for irrigation using ground water (Table 1). However, actual annual irrigation from 1991 through 1993 varied from as little as 321 acres to as much as 568 acres (Table 1). Assessment of potential irrigable land in this report will not be limited to or based on actual current water permits, or on current actual irrigated acreage. Rather it will be based on evaluation of the water and soil resource. In Oliver County three aquifers have been identified as potential sources for irrigation. These are listed on Table 2. There are two possible limiting factors affecting potential irrigation development using ground water. These are (1) irrigable land within practical distance of the water source , and (2) available water of suitable quality in close proximity to irrigable land.

Table 1. Summary of current water permit allocations, and current water use in Oliver County, ND.

WATER SOURCE	PERMITED LAND (ACRES)	IRRIGATED ACRES IN 1991	IRRIGATED ACRES IN 1992	IRRIGATED ACRES IN 1993
Ground Water	764	321	569	556
Surface Water	6,500			
Missouri Mainstem	6,062	2,365	2,299	354
Non Mainstem	437.5	191	139	84

Table 2. Resources for potential irrigation development in Oliver County, ND. EC is the electrical conductivity of water; SAR is the sodium adsorption ratio of water; and Boron is the concentration of boron in water. Potential irrigable acres based on water limitations (column 8) are calculated by multiplying the total acreage (column 7) by the recharge coefficient coefficient in column (6) as described in the text, and by adjusting for water quality (column 5). Land mapped in irrigable soils series, and having a slope of less than 3% (column 10) is calculated from land area mapped in irrigable associations overlying the aquifer (column 9), adjusted for the proportion of the association attributed to soils of irrigation suitable series, and by an adjustment factor (0.50) accounting for slopes greater than 3%. The final estimate of potential irrigation development is half of column 10. **Bold type** indicates most limiting estimate of potential irrigation, used in final estimates of potential irrigation dev elopment. (c) indicates confined aquifer, (u) is unconfined, and (u/c) is variably confined and unconfined.

(1) WATER SOURCE	(2) ECE %<1500 µS/cm	(3) SAR %< 6	(4) BORON %<2 mg/L	(5) WATER QUALITY COEFFICIENT	(6) RECHARGE COEFFICIENT	(7) AREA OVERLYING AQUIFER acres	(8) POTENTIAL IRRIGABLE ACRES-WATER LIMIT acres	(9) LAND MAPPED IN IRRIGABLE ASSOCIATIONS acres	(10) LAND MAPPED IN IRRIGABLE SOIL SERIES, SLOPE < 3% acres	(11) POTENTIAL IRRIGABLE SOIL OVERLYING AQUIFER acres
Missouri River u/c	83	73	100	0.73	0.17	23,840	**2,958**	22,000	11,000	5,500
Square Butte Creek * u/c	-	-	-	0.49*	0.17	9,312	776	2,400	1,200	**600**
Undifferentiated* u/c	-	-	-	0.49*	0.17	608	**50**	608	304	152
Total						33,760	3,784	25,008	12,504	6,252

* Water quality data not available. Use estimate based on similar aquifers in neighboring counties.

Total Irrigable Soils

If water were not limiting there would be ample irrigable land in Oliver County. There are approximately 1,172,743 acres in Oliver County. A soil association map (USDA-SCS, 1975) is provided on Figure OI-1. Of this, there are about 97,780 acres of Group 1 (irrigable without limitations, slope less than 3 %) soils based on Oliver County SCS soil survey tabulations. There are an additional 43,867 irrigable acres in the Group 2 category (irrigable with limitations). Usually the limitation is fineness of soil, which requires limited rates of water application. Soils requiring extensive surface or subsurface drainage are considered as non irrigable in this study. Thus, based on soil suitability alone, there are about 141,647 acres of potentially irrigable land. Estimates of total irrigable and conditionally irrigable soil in Oliver County were also provided previously in an NDSU study (Omodt, 1982, written communication). The NDSU estimate was about 141,000 acres of irrigable land in Oliver County.

Estimates of federal and state lands are approximately 7,017 acres, and town lands are estimated at 7,040. Coal lands are 2,702 acres. The total of excluded land is 16,759 acres. About 12 % of all lands are classified as irrigable or conditionally irrigable. Adjusting excluded land for the percent irrigable, and subtracting the result (2,015 acres) from the total of irrigable land, **gives a final estimate of about 140,000 of potentially irrigable land in Oliver County.** A map of soil Groups (irrigable, conditionally irrigable, and non irrigable) as defined for this study is provided on Figure OI-2. At least half of the irrigable land in Oliver County is conditionally irrigable.

Estimates of Irrigable Soil Overlying Aquifers

The overall estimates of irrigable soils discussed above were taken from soil survey summary tables and were adjusted for slopes greater than 3%. Estimates of irrigation-suitable soil overlying aquifers were calculated by integrating the areas of mapped soil associations within mapped aquifer boundaries (Table 2, column 9). A map of soil associations in Oliver County is shown on Figure OL-1. A map of irrigable and conditionally irrigable soil groups is shown on Figure OL-2. Areas mapped to soil associations considered to be predominantly irrigable were adjusted by the percent of soil series within the association considered to be irrigable. In addition, irrigable series were adjusted to account for slopes greater than 3% using a factor of 0.5 (Table 2, column 10). Finally, a 1/2 contingency factor was applied to all estimates of irrigable soil area. Results in Table 2, column 11 indicate that in Oliver County **about 6,000** (6,252) **acres of land overlying aquifers would be considered as potentially irrigable based on soil suitability alone.**

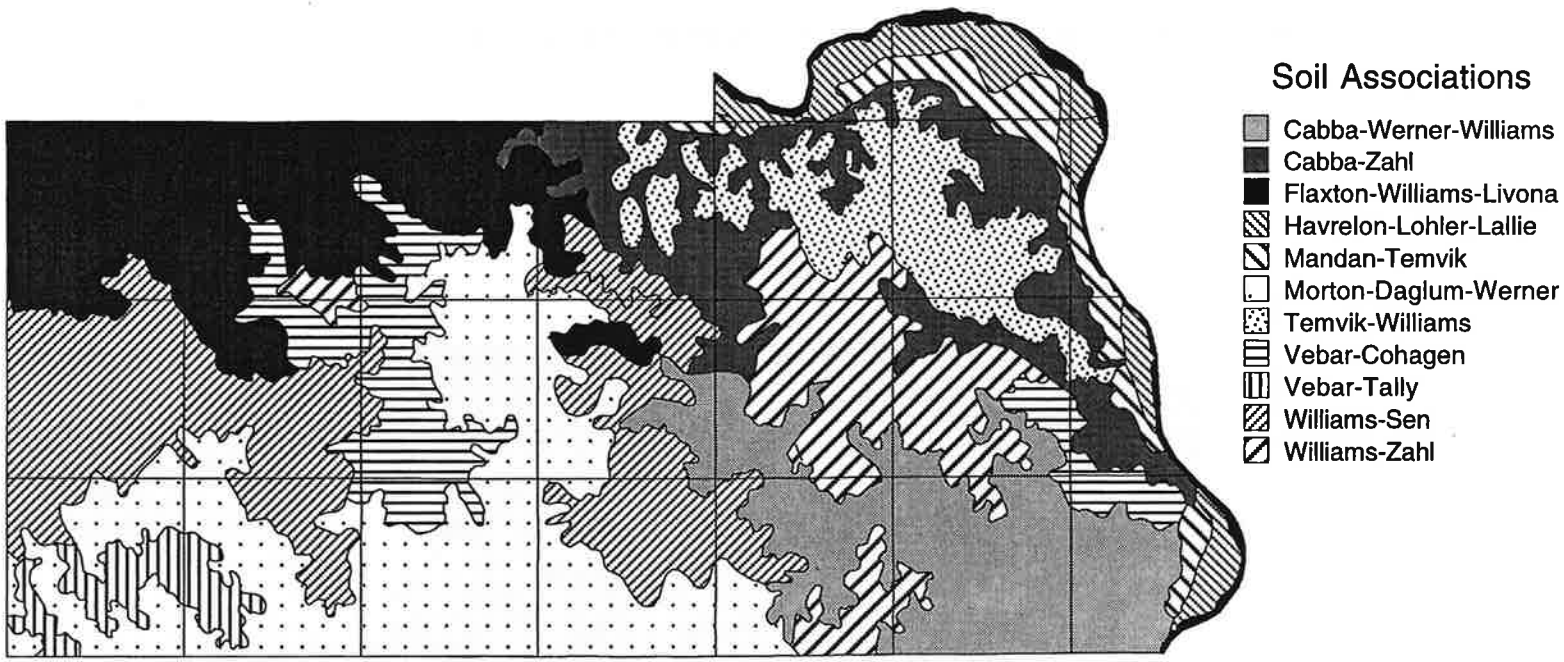

Figure Ol-1. Soil association map of Oliver County ND. (From Oliver County Soil Survey, USDA-SCS , Unpublished 1975).

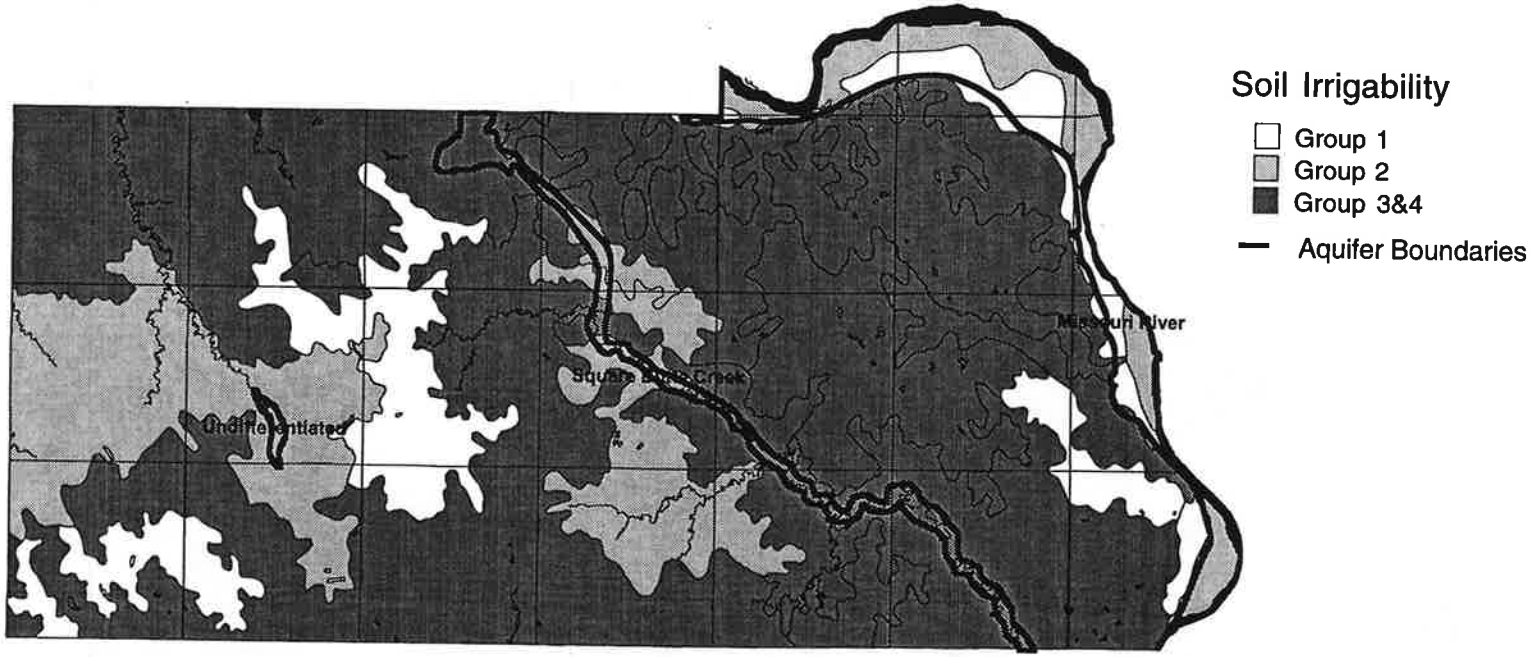

Figure OI-2. Map of boundaries of the principal aquifers in Oliver County, ND. (From Carlson 1973).

Irrigable Land Overlying Aquifers Based on Water Supply Limitations

Supplies of water suitable for irrigation are limited in most aquifers. Estimates of water available for potential irrigation development are based on an estimated recharge of 0.3 inches per year for deeper confined aquifers in glacial till, 1.2 inch per year for shallow confined aquifers, 2 inches per year for aquifers that are partly confined, and partly unconfined, and 3 inches per year for unconfined aquifers. Irrigable acreage for each aquifer is then calculated by assuming an average of 12 inches per acre per year irrigation. The recharge coefficient is the estimated recharge divided by the 12-inch use estimate. Recharge coefficients calculated for 0.3, 1.2, 2.5, and 4 inches are 0.025, 0.1, 0.17, and 0.25, respectively. Slightly lower recharge estimates and sustained yield coefficients are used for Oliver County, than for counties farther east because of somewhat lower (about 2 inches per year) average annual precipitation. In Oliver County all of the shallow aquifers are variably confined and unconfined. All of the recharge coefficients on Table 2 are therefore 0.17 (Table 2, column 6).

A further limitation on water supply for irrigation is water quality. Probability plots for electrical conductivity (ECE), sodium adsorption ratio (SAR), and boron were graphed for all water samples in the North Dakota State Water Commission data base, for each aquifer. Estimated sustainable yield was multiplied by the most limiting fraction of suitable water based on these three chemical parameters (Table 2, column 5). Aquifers having inadequate data were adjusted using a conservative water quality factor (0.49) based on similar measurements from aquifers in neighboring counties. **A total of about 3,500** (3,784) **acres was estimated as potentially irrigable, based on water supply limitations in Oliver County** (Table 2, column 8).

Potential Irrigation Development from Ground Water in Oliver County

The most limiting factor in Table 2 [water limiting (column 8); or soil limiting (column 11)] is used to estimate potential irrigation development from ground water in Oliver County. Water is limiting for the Missouri River aquifer, while land is limiting for the Square Butte Creek aquifer. All land parcels of less than 130 acres are counted as 0. Based on Table 2, **about 3,500 acres are estimated as having potential for irrigation development from ground water in Oliver County.** This compares with an actual current water permit allocation of 764 acres, and actual current annual water use of close to 600 acres.

Additional Comments

Most of the aquifers considered for potential development have relatively low probabilities (49 to 73% chance) of obtaining good quality water for irrigation from a given well. Although development from such supplies is possible, there are additional problems of finding water of suitable quality which add to the expense and difficulty of development. **The ground-water supplies in Oliver**

County are not likely situated for large-scale development in a short period of time. Rather it is expected that irrigation using ground-water would develop slowly, and on a case by case basis.

IRRIGATION DEVELOPMENT USING SURFACE WATER

Surface water sources in Oliver County include the Missouri river (main stem), Square Butte Creek, Antelope Creek, and small land-locked lakes (Table 1). Of these the Missouri River represents a large potential water supply. In Oliver County there are currently 6,500 acres permitted for irrigation from surface water sources. Actual irrigation from 1991 through 1993 was between 400 and 3,000 acres. Statistics for surface waters are presented on Table 1.

In this study, only the Missouri River will be considered as a possible source of water for substantial irrigation development. Smaller streams may be ephemeral and provide unreliable supplies of water for dry periods. Small lakes are also excluded as potential water sources because of the complexities involved with lake hydrology and because of competing recreational and wildlife interests. While some lake waters may be available for use, they would have to be considered as individual cases. Lakes should not be considered as a potential large source of water in Oliver County.

All of the land here considered for surface-water source irrigation lies in the Missouri River Flood Plain, and in a tract of land extending Northwestward from the Missouri River north of Square Butte Creek which has unconditionally irrigable soil (Figure OI-2). Land potentially suitable for irrigation development using surface water is shown on Figure OI-3. Total area is 14,880 acres. Of this, approximately 1,600 acres is government land. Land available for potential irrigation development is thus 13,280 acres. After applying a contingency factor of 1/2 the final estimate is 6,640 acres for potential surface-water irrigation development. **Estimated irrigation development from surface water in Oliver County is about 6,500 acres.** Estimated potential development matches almost exactly with current permit allocations. While it must be remembered that a contingency factor of 1/2 has been applied, and that additional development may be possible, it is concluded that potential for expanded irrigation from surface water in Oliver County is not large.

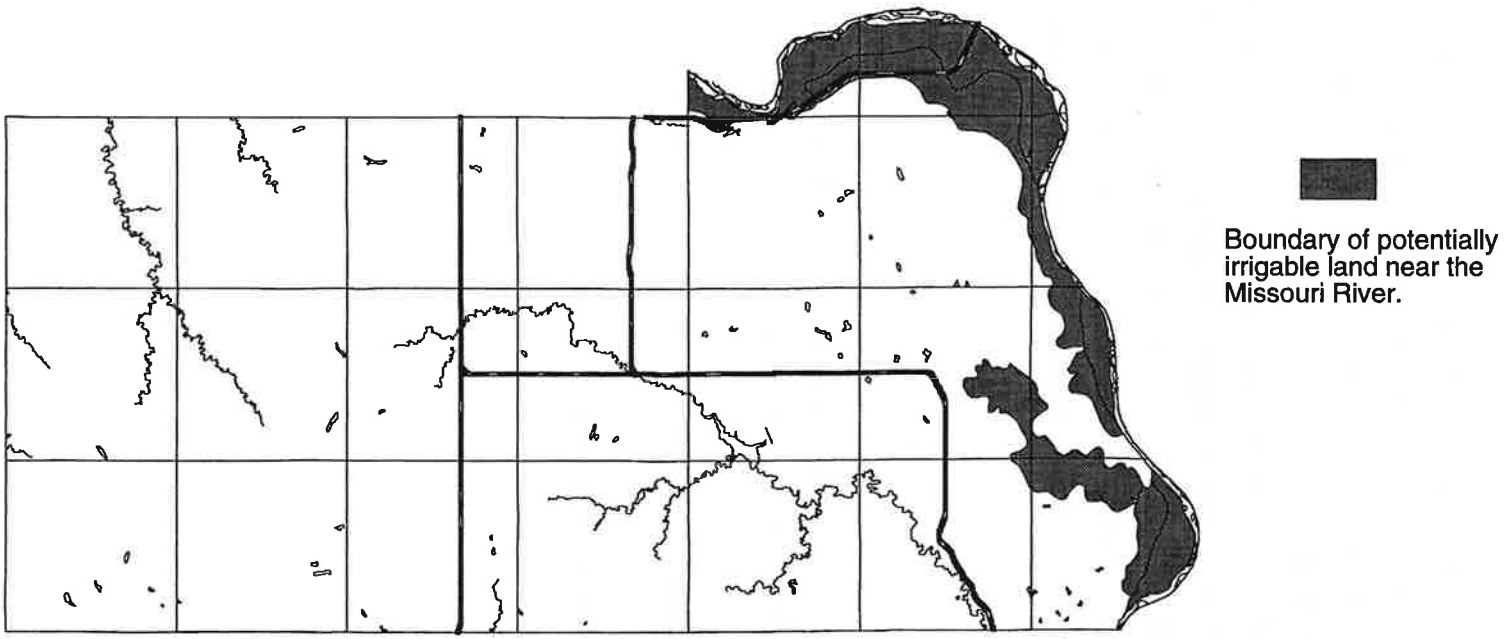

Figure OI-3. Map of land potentially irrigable using water from the Missouri River.

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT

Approximately 3,500 acres of potential irrigation from ground water, and approximately 6,500 acres of potential irrigation from surface water has been estimated for Oliver County. The ground-water estimate includes about 1,500 acres of irrigation from the Missouri River aquifer. However, the Missouri River aquifer is overlain almost entirely by Missouri River bottom land that is potentially irrigable from the Missouri River itself. Thus, 1,500 acres is excluded from the sum of potential ground water and surface water irrigation. **Total potential irrigation development from all sources is thus estimated to be about 8,500 acres.** This total does not differ greatly from the current total water allocation for Oliver County (Table 1.) It appears that some expanded irrigation development may be possible in Oliver County, but that increases in irrigation would likely be limited.

REFERENCES

Carlson, C. G. 1973. Ground-water Resources of Mercer and Oliver County, North Dakota. County Ground-Water Studies 15, Part III. North Dakota State Water Commission. Bismarck, ND.

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Potential Irrigation Development in Pierce County, North Dakota

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT FOR PIERCE COUNTY

Three aquifers in Pierce County provide most of the water for potential irrigation development. These are the Kilgore, the New Rockford, and the Pleasant Lake aquifers. About 14,500 acres overlying these aquifers have soils classified as irrigable or conditionally irrigable, have slopes of less than 3 %, are free from substantial surface and subsurface drainage requirements, and lie in parcels of sufficient size for irrigation. In this study, estimates of potentially irrigable land are based on total land classified as irrigable, multiplied by a contingency factor of 1/2 to account for potential error, and land owner preferences regarding development. The contingency factor is also intended to lend a conservative bias to this report. Application of the contingency factor results in an estimate of at least 7,000 acres of irrigable land in Pierce County.

Water quality for irrigation is variable. About 70% of water samples taken from the Kilgore and New Rockford aquifers are of suitable quality for irrigation, based on the criteria of this study. Estimates of long-term sustainable yield indicate that sufficient water for about 5,000 acres of irrigation is possible on a long-term basis.

Potential irrigation development is estimated by summing the most limiting resource (irrigable land or water) for each aquifer. **Results indicate that development of at least 4,500 acres for irrigation should be feasible in Pierce County.** Estimates of potential irrigation development in this report compare with a total of 1,561 acres currently permitted for irrigation in Pierce County. This estimate is likely conservative, and it would not be implausible that some additional acres of irrigation might be developed in carefully monitored stages.

POTENTIAL IRRIGATION DEVELOPMENT IN PIERCE COUNTY NORTH DAKOTA

The purpose of this report (chapter) is to provide an evaluation of land and water available for potential irrigation development in Pierce County. Methods of assessment used in this report were designed to provide a conservative estimate. These methods were described in a previous introductory section. It is emphasized that the findings of this report are based on general information. They are preliminary, and they should not be used for individual project planning without further local in-depth analysis. For the sake of continuity in computation, data on computation tables are provided to the nearest digit. However, this should not lead to the conclusion that this report can estimate acreage with such a high level of precision. **In the text of this report, the final summary estimates resulting from table computations are rounded to the nearest 500 acres.** These final rounded numbers reflect more appropriately the general character of these estimates.

In Pierce County there are currently 11 irrigation permits for a total of 1,561 acres. Actual water use varies. Between 1991 and 1993 largest irrigated acreage was 656 in 1992. Least irrigation (401 acres) occurred in 1993, which was an extremely wet year.

IRRIGATION DEVELOPMENT FROM GROUND WATER

Assessment of potential irrigable land in this report will not be limited to or based on actual current water permits, or on current actual irrigated acreage. Rather it will be based on evaluation of the water and soil resource. In Pierce County three principal aquifers have been identified as potential sources for irrigation. These are listed on Table 1. There are two possible limiting factors affecting potential irrigation development using ground water. These are (1) irrigable land within practical distance of the water source , and (2) available water of suitable quality in close proximity to irrigable land.

Total Irrigable Soils

There are approximately 627,015 acres in Pierce County. According to a study conducted by North Dakota State University (NDSU) there are about 512,452 acres of irrigable and conditionally irrigable land in Pierce County (Omodt, written communication, 1982). Of this most, or about 63 %, is classified as conditionally irrigable because of slope, drainage requirements, or slowness of internal drainage.

Table Pi-1. Resources for potential irrigation development in Pierce County, ND. ECE is the electrical conductivity of water; SAR is the sodium adsorption ratio of water; and Boron is the concentration of boron in water. Potential irrigable acres based on water limitations (column 8) are calculated by multiplying the total acreage (column 7) by the recharge coefficient coefficient in column (6) as described in the text, and by adjusting for water quality (column 5). Irrigable land having slope of less then 3%, and not requiring drainage (column 10) is calculated from land area mapped in irrigable associations overlying the aquifer (column 9), adjusted for the proportion (0.17) of quarter sections available for irrigation without drainage, based on soil survey maps . The final estimate of potential irrigation development is half of column 10. **Bold type** indicates most limiting estimate of potential irrigation, used in final estimates of potential irrigation development. (c) is confined, (u) is unconfined, and (c/u) is variably confined and unconfined.

(1) WATER SOURCE	(2) ECE	(3) SAR	(4) BORON	(5) WATER QUALITY COEFFICIENT	(6) RECHARGE COEFFICIENT	(7) AREA OVERLYING AQUIFER	(8) POTENTIAL IRRIGABLE ACRES-WATER LIMIT	(9) LAND MAPPED IN IRRIGABLE ASSOCIATIONS	(10) LAND MAPPED IN IRRIGABLE SOIL SERIES, SLOPE < 3%	(11) POTENTIAL IRRIGABLE SOIL OVERLYING AQUIFER
	%<1500 µS/cm	%< 6	%<2 mg/L			acres	acres	acres	acres	acres
Kilgore -c/u	-	-	-	0.7*	0.1	20,992	**1,469**	20,992	3,569	1,784
Pleasant Lake -c/u	100	97	100	0.97	0.1	17,036	1,652	17,036	2,986	**1,493**
New Rockford -c	70	70	98	0.7	0.05	46,502	**1,628**	46,502	7,905	3,952
undifferentiated	-	-	-	0.7*	0.05	2,624	92	0	0	**0**
Total						87,154	4,841	84,530	14,460	7,229

* No water quality data were available. Used probability of most limiting case.

The classification used in this report is a much more restrictive subset of that used in the NDSU study. A soil association map (USDA-SCS, unpublished) is provided on Figure Pi-1. All soils requiring extensive surface or internal drainage are excluded from consideration, and all soils having slopes of more than 3 % are also excluded. Using the criteria of this study, about 192,865 acres are classified as Group 1 (irrigable without limitations, slope less than 3 %) soils based on Pierce County SCS soil survey tabulations. There are an additional 127,720 irrigable acres in the Group 2 category (irrigable with limitations). Thus, based on soil suitability alone, there are about 320,585 acres of potentially irrigable land.

All federal, state, and municipal land is excluded from the potentially irrigable acres. There are about 22,179 acres of state and federal land, and about 8,960 acres of municipal land, for a total of about 31,139 acres of government land. About 51 % of all land in Pierce County is classified as irrigable according to standards of this study. Applying this proportion to government land gives 15,881 acres of excluded land that might be considered irrigable. After subtracting estimated irrigable government land, approximately **304,500 acres** (304,704 acres) **would be considered to be potentially irrigable based on soil factors alone.** A map of soil Groups (irrigable, conditionally irrigable, and non irrigable) as defined for this study is provided on Figure Pi-2.

Estimates of Irrigable Soil Overlying Aquifers

The overall estimates of irrigable soils discussed above were taken from soil survey summary tables and were adjusted for slopes greater than 3%. Estimates of irrigation-suitable soil overlying aquifers were calculated by integrating the areas of mapped soil associations within mapped aquifer boundaries. Area mapped to soil associations considered to be predominantly irrigable were adjusted by the percent of individual soil series within the association classified as irrigable. In addition, irrigable soil series areas were adjusted to account for slopes greater than 3%. However, the large number of wetlands and potholes in Pierce County require additional consideration of potential field area which is free of potholes in tracts sufficiently large to irrigate. Thus, for Pierce County, soil survey photo maps were viewed and judged for full quarter sections free of large potholes. Of 273 quarter sections surveyed, 17% were sufficiently free from potholes and lakes to allow for the operation of a center pivot. This factor (0.17) was applied directly to the mapped area of irrigable soil associations overlying each aquifer to estimate the total amount of irrigable soils (Table 1, column 10). Finally, a 1/2 contingency factor was applied to all estimates of irrigable soil area. Results in Table 1, column 11, indicates that **about 7,000 acres** (7,229 acres) **of land overlying aquifers would be considered as potentially irrigable based on soil suitability alone.** Irrigable land is well distributed over the Kilgore, Pleasant Lake, and New Rockford aquifers.

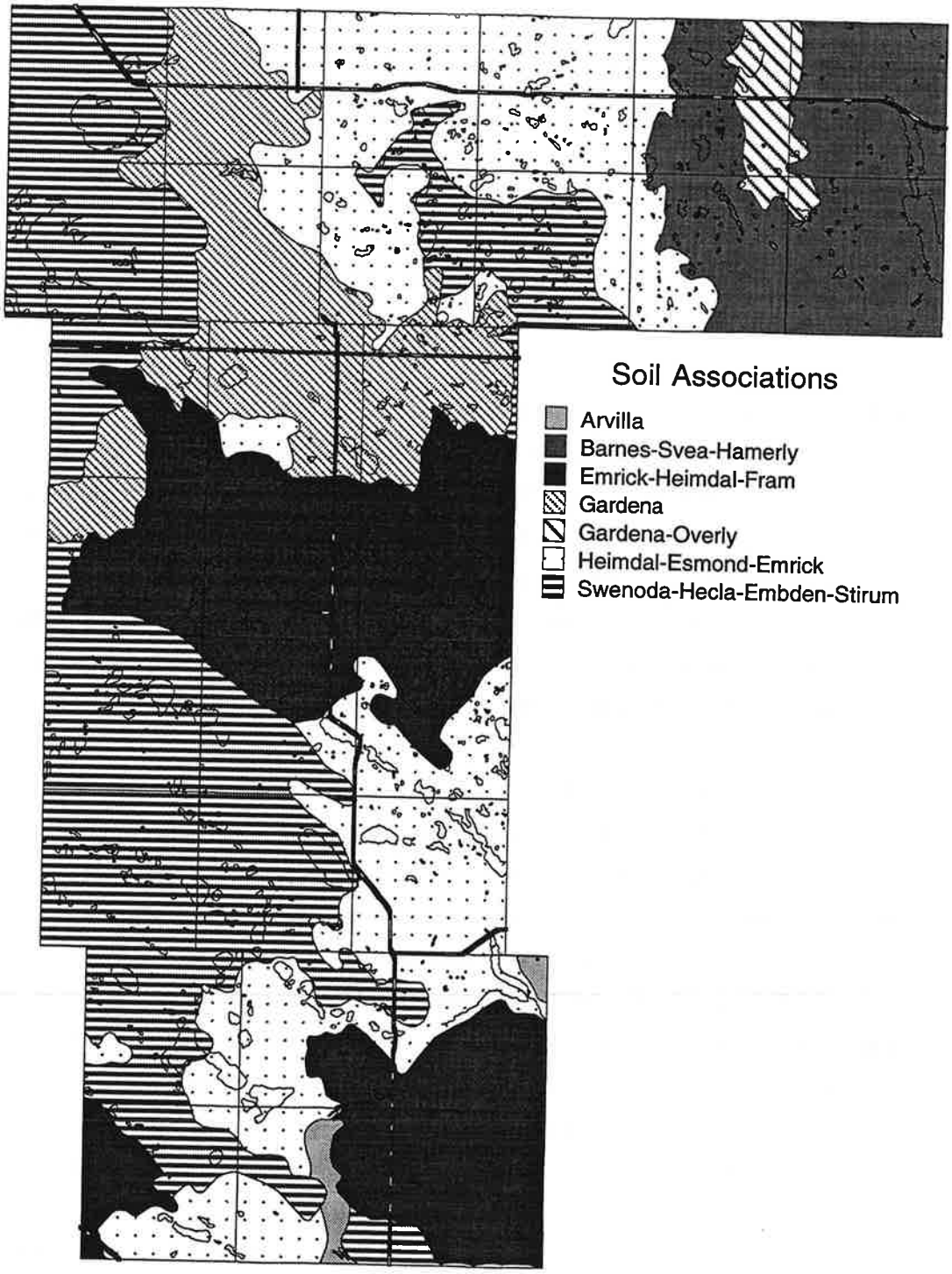

Figure Pi-1. Soil association map of Pierce County ND. (From Pierce County Soil Survey, USDA-SCS , 1978).

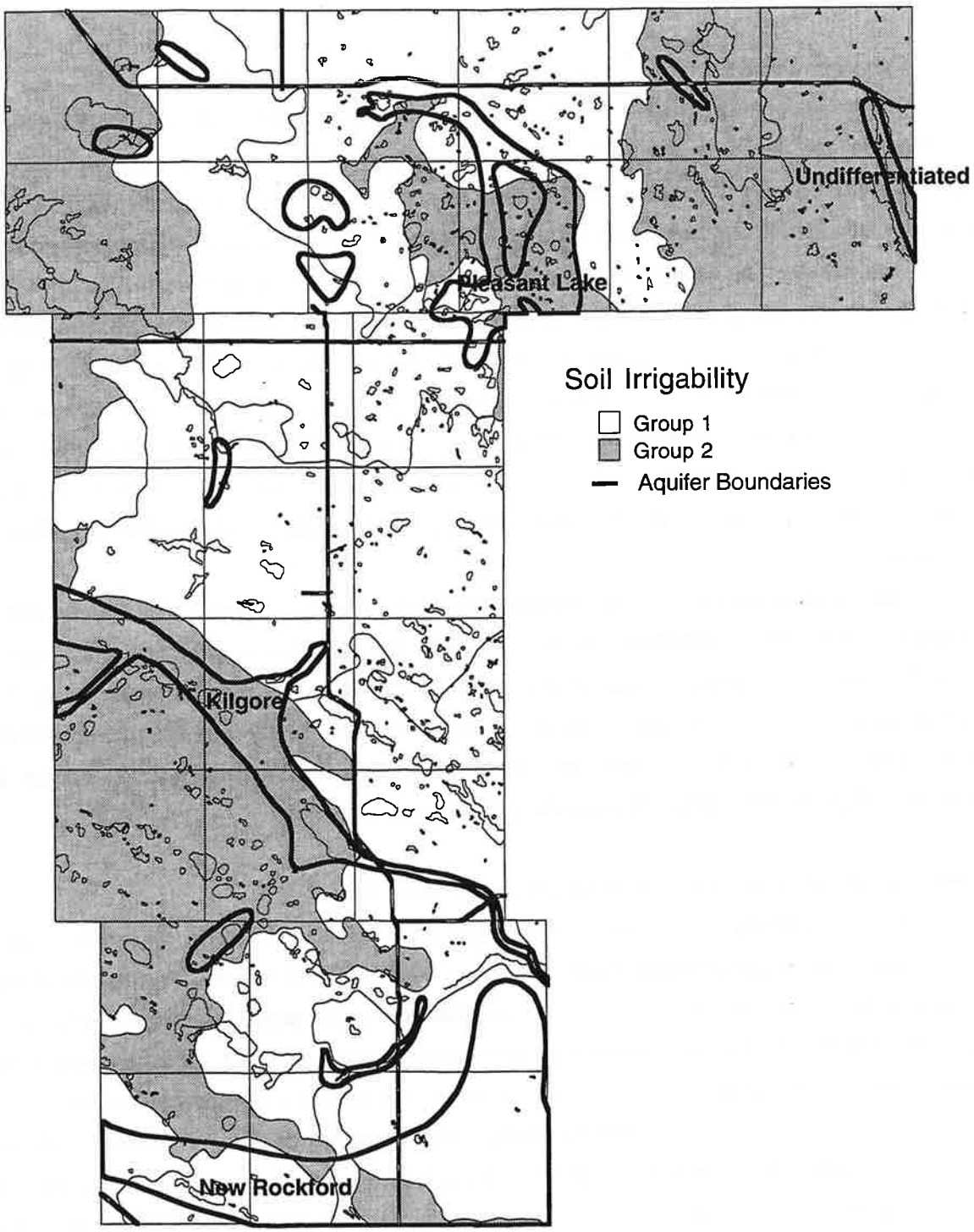

Figure Pi-2. Map of boundaries of the principal aquifers in Pierce County ND. (From Randich, 1977).

Potential Irrigation Development Over Aquifers Based on Water Supply Limitations

Ground-water resources in Pierce County have variable quality for irrigation use. Between 70 and 100 % of the ground water from aquifers considered on Table 1 are of suitable quality for irrigation. Water quality is evaluated on the basis of suitable electrical conductivity (ECE), sodium adsorption ratio (SAR), and Boron concentration (Table 1). Estimates of water available for potential irrigation are based on an estimated recharge of 0.3 inches per year for deeper confined aquifers in glacial till, 1.2 inch per year for shallow confined aquifers, 2.5 inches per year for aquifers that are partly confined, and partly unconfined, and 4 inches per year for unconfined aquifers. Irrigable acreage for each aquifer is then calculated by assuming an average of 12 inches per acre per year irrigation. The recharge coefficient is the estimated recharge divided by the 12-inch use estimate. Recharge coefficients calculated for 0.3, 1.2, 2.5, and 4 inches are 0.025, 0.1, 0.21, and 0.33, respectively. In some cases, depending on the aquifer, ranges of values between these coefficients are selected.

Irrigation acreage based on sustainable water use is further adjusted by the water quality coefficient, which is the probability of obtaining water suitable for irrigation in a given well (Table 1, column 5). The most limiting parameter (of ECE, SAR, Boron) is used to adjust for water quality. The resulting irrigable acreage estimate based on recharge and water quality is in Table 1, column (8). **About 5,000 acres** (4,841 acres) **are estimated as potentially irrigable, based on estimates of available water of suitable quality for irrigation.**

Potential Irrigation Development from Ground Water in Pierce County

The most limiting factor in Table 1 [water limiting (column 8); or soil limiting (column 11)] is used to estimate potential irrigation development from ground water in Pierce County. Parcels of land less than 130 acres are not included in the sum of potentially irrigable acres. Development from the Kilgore and New Rockford aquifers is limited by water rather than available soil. Development from the Pleasant Lake aquifer is limited by irrigable soil. However, in most cases soil and water resources are fairly closely matched. **The sum of potentially irrigable acres based on the most limiting resource is about 4,500 acres** (4,590 acres). If the 1/2 contingency factor were not applied to available soil, the total would be closer to 5,000 acres. This compares with about 1,396 acres already permitted for irrigation using ground water in Pierce County.

Additional Comments

It is considered that the estimate of 4,500 to 5,000 acres of irrigation development (of which about 1,396 acres are already permitted) is conservative, and that substantial additional development would be possible. Estimates were based on computations of sustained yield. Some additional

development might be allowable on the basis of limited mining, and might be sustainable for many years.

IRRIGATION USING SURFACE WATER

There are currently 166 acres approved for irrigation using surface water in Pierce County. Of this, annual use is usually about 150 acres. Minimum recorded use was 33 acres in 1993. There are no major rivers or streams in Pierce County to provide a reliable water supply. While there are numerous small lakes, potholes, and sloughs in Pierce County, these are excluded as potential water sources because of the complexities involved with lake hydrology and because of competing recreational and wildlife interests. While some lake waters would likely be available for use, they would have to be considered as individual cases. Total current irrigation from surface water is insubstantial, and does not significantly effect the overall total of potential development.

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT

Approximately 4,500 to 5,000 acres of potential irrigation, all from ground water, appears to be available for development in Pierce County. Additional development of might be feasible under appropriate conditions, but would likely have to be implemented in carefully monitored stages.

REFERENCES

Randich, P.G. 1977. Ground-water Resources of Pierce County, North Dakota. County Ground-Water Studies 18, Part III. North Dakota State Water Commission. Bismarck, ND.

Omodt, Hollis W. 1982. Irrigability of North Dakota Soils, based on written communication to Larry Knudtson.

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Potential Irrigation Development in Sheridan County, North Dakota

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT FOR SHERIDAN COUNTY

There are five aquifers in Sheridan County which provide water for potential irrigation development. About 18,500 acres overlying these aquifers have soils classified as irrigable or conditionally irrigable, have slopes of less than 3 %, are free from substantial surface and subsurface drainage requirements, and lie in parcels of sufficient size for irrigation. In this study, estimates of potentially irrigable land are based on total land classified as irrigable, multiplied by a contingency factor of 1/2 to account for potential error, and land owner preferences regarding development. The contingency factor is also intended to lend a conservative bias to this report. Application of the contingency factor results in an estimate of at least 9,000 acres of irrigable land overlying aquifers in Sheridan County.

Water quality for irrigation is variable, with much of the water being of poor quality for irrigation. About 50 % of water in the Martin, North Burleigh, and Painted Woods aquifers is of suitable quality for irrigation, based on the criteria of this study. Only 10 % of water in the Butte aquifer would be of suitable quality for irrigation. Estimates of long-term sustainable yield indicate that sufficient water for about 10,000 acres of irrigation is possible on a long-term basis.

Potential irrigation development is estimated by summing the most limiting resource (irrigable land or water) for each aquifer. Results indicate that development of at least 7,500 acres for irrigation from ground water should be feasible in Sheridan County. An additional total of up to 1,500 acres may be developed for irrigation using water from the McClusky Canal. Irrigation development using water from the McClusky Canal would include meeting federal requirements.

Total potential irrigation development using ground water and surface water is about 9,000 acres. Additional irrigation development may be possible, but would likely occur in gradual, carefully monitored stages. Estimates of potential irrigation development in this report compare with a total of 267 acres currently permitted for irrigation in Sheridan County.

POTENTIAL IRRIGATION DEVELOPMENT IN SHERIDAN COUNTY NORTH DAKOTA

The purpose of this report (chapter) is to provide an evaluation of land and water available for potential irrigation development in Sheridan County. Methods of assessment used in this report were designed to provide a conservative estimate. These methods were described in a previous introductory section. It is emphasized that the findings of this report are based on general information. They are preliminary in nature, and they should not be used for individual project siting without further local in-depth analysis. For the sake of continuity in computation, data in computation tables are provided to the nearest digit. However, this should not lead to the conclusion that this report can estimate acreage with such a high level of precision. **In the text of this report, the final summary estimates resulting from table computations are rounded to the nearest 500 acres.** These final rounded numbers reflect more appropriately the general character of these estimates.

Current Irrigation Development

In Sheridan County, the primary source of irrigation water is ground water. Sheridan County has poorly defined external drainage, so that there are no major streams to provide a reliable surface water supply. While there are lakes and ephemeral potholes, these do not provide reliable supplies of water in most cases . There is currently little irrigation development in Sheridan County. In fact, there is only one irrigation permit for 267 acres. Total reported irrigation in Sheridan County from 1991 to 1993 varied narrowly from 270 acres in 1993, to a maximum of 310 acres in 1991 and 1992.

There is currently no approved irrigation using surface water. Because of the lack of major streams, and because of the complexities involved with lake hydrology and competing recreational and wildlife interests, surface waters in Sheridan County are excluded from consideration as sources. While some lake waters would likely be available for use, they would have to be considered as individual cases. The McClusky Canal may provide some water for irrigation. Access to water from the McClusky Canal requires meeting certain federal requirements. These will be discussed briefly in this report. Aside from the McClusky Canal, all potential irrigation will be analyzed using potential ground-water sources.

POTENTIAL IRRIGATION DEVELOPMENT FROM GROUND WATER

Assessment of potential irrigable land in this report will not be limited to or based on actual current water permits, or on current actual irrigated acreage. Rather it will be based on evaluation of

Table 1. Resources for potential irrigation development in Sheridan County, ND. EC is the electrical conductivity of water; SAR is the sodium adsorption ratio of water; and Boron is the concentration of boron in water. Potential irrigable acres based on water limitations (column 8) are calculated by multiplying the total acreage (column 7) by the recharge coefficient coefficient in column (6) as described in the text, and by adjusting for water quality (column 5). Land mapped in irrigable soils series, and having a slope of less than 3% (column 10) is calculated from land area mapped in irrigable associations overlying the aquifer (column 9), adjusted for the proportion of the association attributed to soils of irrigation suitable series, and by an adjustment factor (0.59) accounting for slopes greater than 3%. The final estimate of potential irrigation development is half of column 10. **Bold type** indicates most limiting estimate of potential irrigation, used in final estimates of potential irrigation development. (c) means aquifer is confined with less than 50 feet of overburdon. (c†) means that aquifer is deeply confined, having more than 50 feet of overburdon. (u) means that aquifer is unconfined. (c/u) means that aquifer is variably confined and unconfined.

(1) WATER SOURCE	(2) ECE %<1500 µS/cm	(3) SAR %< 6	(4) BORON %<2 mg/L	(5) WATER QUALITY COEFFICIENT	(6) RECHARGE COEFFICIENT	(7) AREA OVERLYING AQUIFER acres	(8) POTENTIAL IRRIGABLE ACRES-WATER LIMIT acres	(9) LAND MAPPED IN IRRIGABLE ASSOCIATIONS acres	(10) LAND MAPPED IN IRRIGABLE SOIL SERIES, SLOPE < 3% acres	(11) POTENTIAL IRRIGABLE SOIL OVERLYING AQUIFER acres
Butte -c	90	10	100	0.10	**0.05**	5,888	29	1 ,600	566	283
Lake Nettie -c	72	72	96	0.72	**0.06**	120,000	**5,184**	38,400	13,497	6,748
Martin -c /u	-	-	-	0.5*	0.21	30,848	3,239	17,280	4,395	**2,197**
North Burleigh -u	100*	100*	100	0.50	0.333	3,584	596	0	0	**0**
Painted Woods Creek -u	100*	100*	100	0.50	0.333	6,976	1,161	640	158	79
Total						167,298	10,209	57,920	18,616	9,307

* No water quality data were available. Used probability of most limiting case.

the water and soil resource. In Sheridan County five aquifers have been identified as potential sources for irrigation. These are listed on Table 1. There are two possible limiting factors affecting potential irrigation development using ground water. These are (1) irrigable land within practical distance of the water source , and (2) available water of suitable quality in close proximity to irrigable land.

Total Irrigable Soils

There are approximately 633,080 acres in Sheridan County. According to a study conducted by North Dakota State University (NDSU) there are about 394,597 acres of irrigable and conditionally irrigable land in Griggs County (Omodt, written communication, 1982). About nine-tenths of the irrigable soils are classified as conditionally irrigable because of slope, drainage requirements, or slowness of internal drainage.

The classification used in this report is a much more restrictive subset of that used in the NDSU study. A soil association map (USDA-SCS, 1995, Unpublished) is provided on Figure Sh-1. Of this, there are about 53,165 acres of Group 1 (irrigable without limitations, slope less than 3 %) soils based on Sheridan County SCS soil survey tabulations. There are an additional 39,105 irrigable acres in the Group 2 category (irrigable with limitations). Usually the limitation is fineness of soil, which requires limited rates of water application. About 59% of all soils mapped in irrigable series have a slope of less than 3%. Soils requiring extensive surface or subsurface drainage are considered as non irrigable in this study. Thus, based on soil suitability alone, there are about 92,270 acres of potentially irrigable land. Estimates of federal and state lands are approximately 68,100 acres, and town lands are estimated at 3,840 acres, for a total of 71,940 acres of government land. About 15 % of all mapped land is irrigable according to criteria of this study. Applying this proportion to government land results in an estimated 10,700 acres of irrigable land excluded from potential use. After excluding government land, approximately **81,500 acres of land in Sheridan County are potentially irrigable based on soil suitability alone.** However, a substantial portion of this land is inaccessable to suitable irrigation water, or lies on state and federal land that is not available for irrigation.

Irrigable Land Overlying Sheridan County Aquifers

Sheridan County has substantial ground water. About 167,298 acres overlie aquifers in Sheridan County (Table 1). Of this, about 57,920 acres would be mapped in soil associations containing soils considered to be suitable for irrigation. Approximate aquifer boundaries are shown on Figure Sh-2. A map of soil suitability for irrigation is also shown on Figure Sh-2. Potential irrigable soil overlying aquifers in Sheridan County is calculated by multiplying the area mapped to soils of irrigable

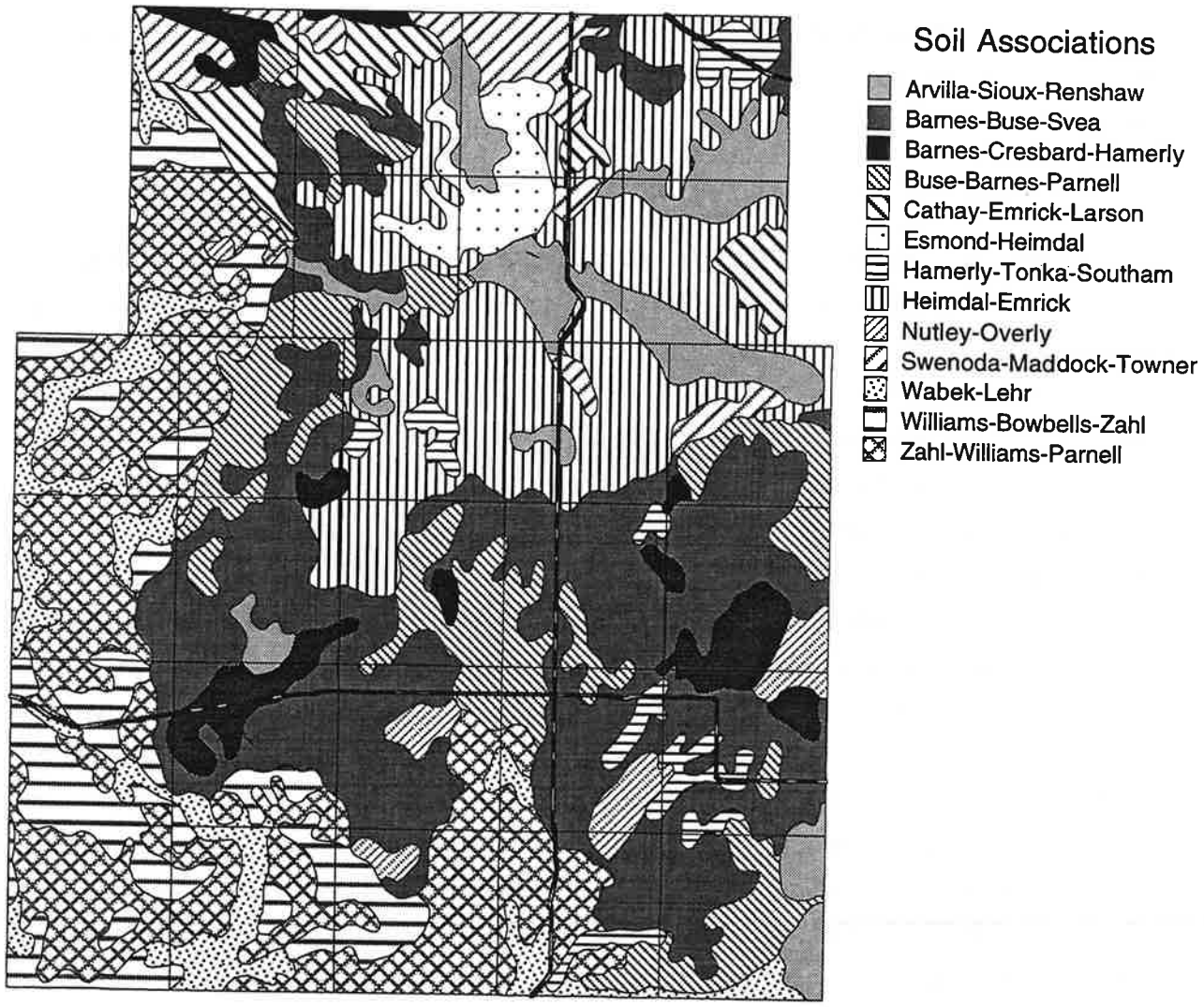

Figure Sh-1. Soil association map of Sheridan County ND. (From Sheridan County Soil Survey, USDA-SCS , Unpublished 1995).

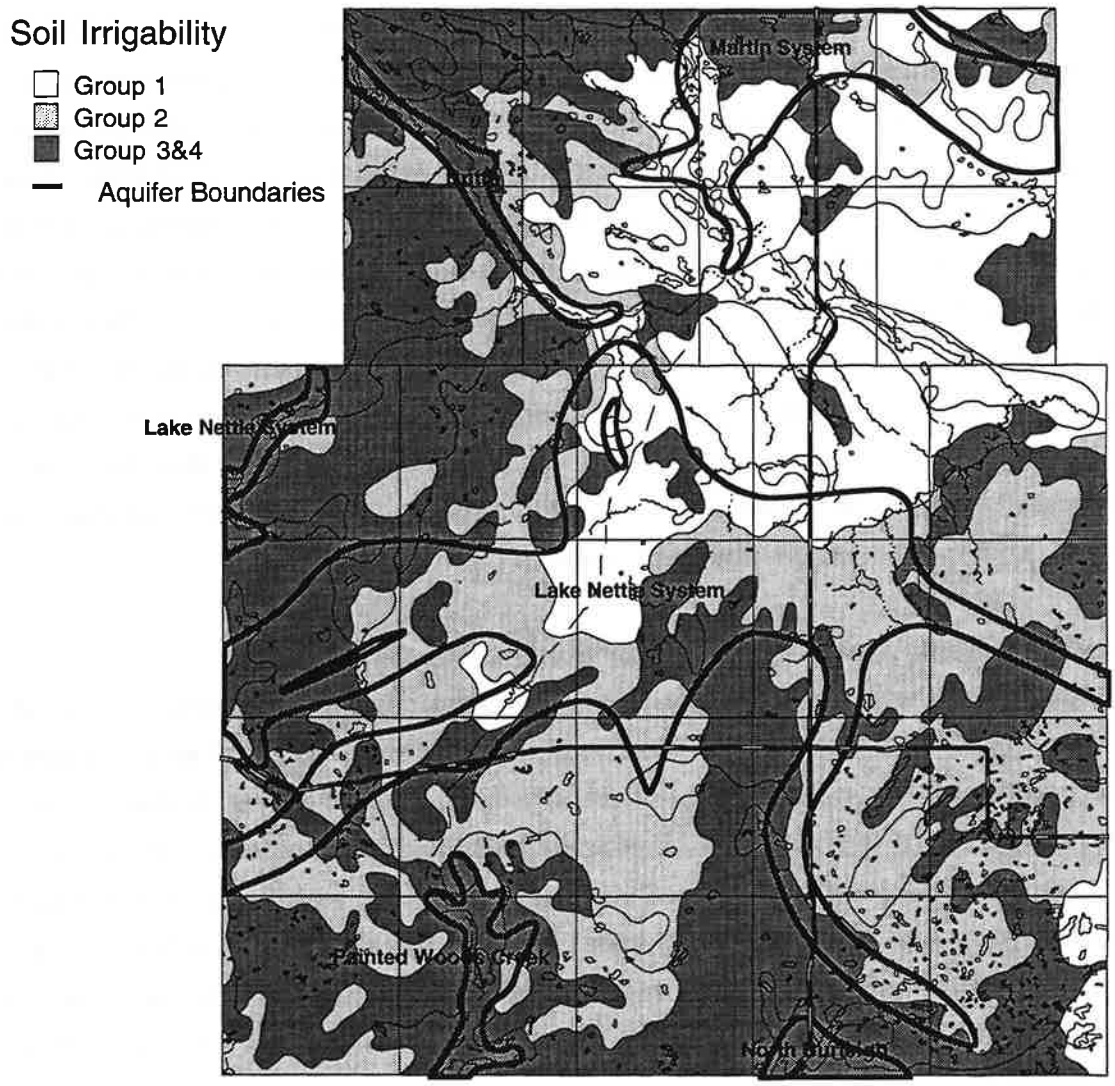

Figure Sh-2. Map of boundaries of the principal aquifers in Sheridan County, ND. (From Burkart, 1983).

associations by the percent of area within the association attributed to irrigation suitable soils series, and by an adjustment factor of 0.59 to account for slopes of more than 3%. The slope factor was computed as the ratio of the area of all irrigable soils in Sheridan County having slopes of less than 3%, divided by the total area of soils in irrigable series in the county.

In Sheridan County, there is a large amount of state and federal land. A substantial portion of this land (about 22,950) overlies aquifers. An adjustment for government land overlying each aquifer was made by determining the ratio of irrigable area to total area overlying each aquifer, and multiplying the government land overlying the aquifer by this ratio. The resulting estimate of irrigable soil area on government land overlying each aquifer is subtracted from the estimated total irrigable area overlying each aquifer to supply an estimate of non government irrigable land. A total of 18,616 acres of land overlying aquifers was found to be irrigable. Total estimated irrigable soils overlying each aquifer were multiplied by a 1/2 factor to account for error, and for local preference. Results indicate that about 9,307 total acres might be available for irrigation, based on irrigable soils overlying aquifers (Table 1, column 11). However, application of a 1/2 contingency factor and accounting for government land may have provided an underestimate. **The reader should consider that there is an approximate minimum of 9,000 acres of total irrigable land overlying aquifers and available for development in Sheridan County.**

Irrigable Land Overlying Aquifers Based on Water Supply Limitations

Ground-water resources in Sheridan County have moderate irrigation potential. About half to three quarters of the ground water is of suitable quality for irrigation. Estimates of water available for potential irrigation are based on an estimated recharge of 0.3 inches per year for deeper confined aquifers in glacial till, 1.2 inch per year for shallow confined aquifers, 2.5 inches per year for aquifers that are partly confined, and partly unconfined, and 4 inches per year for unconfined aquifers. Irrigable acreage for each aquifer is then calculated by assuming an average of 12 inches per acre per year irrigation. The recharge coefficient is the estimated recharge divided by the 12-inch use estimate. Recharge coefficients calculated for 0.3, 1.2, 2.5, and 4 inches are 0.025, 0.1, 0.21, and 0.33, respectively.

While such simplified discrete numbers can be applied in some circumstances, many aquifers are comprised of highly complex systems of coarse deposits, varying from deeply buried to surficial positions. In such cases, an adjustment to the recharge coefficients is made based on an assessment of aquifer surfaces indicated by drill log information on the county-study maps. Resulting estimated recharge coefficients are shown on Table 1, column 6. Irrigation acreage based on sustainable water use is then calculated by multiplying the total area overlying the aquifer by the recharge coefficient.

Irrigation acreage based on sustainable water use, in turn, is adjusted by the water quality

coefficient, which is the probability of obtaining water suitable for irrigation in a given well (Table 1, column 5). The most limiting parameter [of electrical conductivity (ECE), sodium adsorption ratio (SAR), and Boron] is used to adjust for water quality. The resulting irrigable acreage estimate based on recharge and water quality is in Table 1, column (8). **About 10,000 acres would estimated as potentially irrigable, based on estimates of available water of suitable quality for irrigation.**

Total Potential Irrigation Development From Aquifers

Potential irrigation development is calculated using the most limiting of the above criteria for each aquifer. If the overlying soil is most limiting, soil criteria are used. If water supply is limiting, the water supply criterion is used. For Sheridan County, both potential water supply and suitable land are limiting. Water is estimated to be limiting for the Butte and Lake Nettie aquifers, while suitable land is estimated to be limiting for the Martin, North Burleigh, and Painted Woods aquifers. In summing, the most limiting amount of irrigable land estimated for each aquifer using both soils and water availability is considered for each aquifer. Also, any land parcels smaller than a quarter section are not included. The resulting sum for Sheridan County is 7,381 acres. **The estimate of total potential irrigation development in Sheridan County is thus about 7,500 acres.** If the half contingency factor were not applied to the available soils, the amount might be as much as 8,500 acres. This compares with 267 acres currently permitted for irrigation in Sheridan county.

Additional Comments

The 7,500 to 8,500 acre estimate is likely conservative. Further exploration might locate additional water-bearing deposits of limited size in Sheridan County. In addition, estimates for potential development are based on sustainable yield for an indefinite period. A reasonable and limited level of mining might be allowable where there is large aquifer storage, and such additional use could be applied for many years in some cases. This possibility would have to be evaluated on an individual aquifer basis. Finally, the reader is cautioned that the computation methods are general in nature, and on any given aquifer may be overly generous, or excessively limited. To a certain degree, such variances in estimation should cancel in the overall evaluation of the county, and in the overall Central North Dakota region considered in this report.

IRRIGATION POTENTIAL FROM THE McCLUSKY CANAL

Under the Garrison Diversion Unit Reformulation Act of 1986, water for about 4,000 acres of irrigation should be available from the McClusky canal along its entire length, which includes portions in McLean, Burleigh, and Sheridan Counties. According to Jim Weigal of the Garrison Conservancy District, individuals interested in irrigation development should first contact the U. S. Bureau of Reclamation (USBR) area office in Bismarck, North Dakota. The USBR will conduct a survey to determine if soils in the proposed area are suitable for irrigation. If soils are suitable, a water permit will be required from the North Dakota State Water Commission, and a service contract outlining landowners responsibilities and liabilities (with water fees) will be established with the USBR. Crops irrigated from the McClusky Canal will be subject to federal crop program limitations. Under current rules only non-program crops such as potatoes and vegetable crops or alfalfa could be irrigated.

Assessment of soil suitability is performed by the USBR, using standards that may exclude some of the heavier soils used in our assessment. The 4,000 acres of irrigation allocation allowed in the Garrison Diversion Unit Reformulation Act of 1986 was based on a preliminary soil survey by U.S. Bureau of Reclamation planners. Maps of land considered irrigable in McLean County are available from the USBR. In 1988 the McClean County Water Resource District indicated that 2,560 acres were considered to be potentially irrigable from the McClusky Canal in McLean county . For purpose of this report it will be assumed that the remaining portion **(water for about 1,500 acres) would be available from the McClusky Canal for irrigation in Sheridan County.** However, a larger portion of the 4,000 acres of irrigation available from the McClusky Canal may be available for Sheridan County if a detailed survey of soils would indicate sufficient suitable soils, and if McLean County has not first obtained permits for the water.

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT

A starting estimate of about **9,000 acres may be available for irrigation in Sheridan County,** from ground-water sources, and from the McClusky Canal. More development may be found to be feasible as development progresses.

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Potential Irrigation Development in Stutsman County, North Dakota

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT FOR STUTSMAN COUNTY

There are twenty-one aquifers in Stutsman County. However, for many of these aquifers the overlying soils are non irrigable. The single largest source of irrigation water in Stutsman County is the Spiritwood aquifer, which underlies most of the southeastern portion of the county. Smaller but significant aquifers are the Homer, Jamestown, Midway, Montpelier, and Ypsilanti aquifers. About 63,000 acres overlying aquifers in Stutsman County have soils classified as irrigable or conditionally irrigable, have slopes of less than 3 %, are free from substantial surface and subsurface drainage requirements, and lie in parcels of sufficient size for irrigation. In this study, estimates of potentially irrigable land are based on total land classified as irrigable, multiplied by a contingency factor of 1/2 to account for potential error, and land owner preferences regarding development. The contingency factor is also intended to lend a conservative bias to this report. Application of the contingency factor results in an estimate of at least 31,500 acres of irrigable land in Stutsman County.

Water quality for irrigation is variable. About 50% of water samples collected from the Spiritwood aquifer are of suitable quality for irrigation, based on the criteria of this study. Water quality from other aquifers varies from 50% to 100% suitable for irrigation. Estimates of long-term sustainable yield indicate that sufficient water for about 19,000 acres of irrigation is possible on a long-term basis.

Potential irrigation development is estimated by summing the most limiting resource (irrigable land or water) for each aquifer. Results indicate that development of at least 7,000 acres for irrigation should be feasible from ground water in Stutsman County. This compares with a total of 6,776 acres currently permitted for irrigation using ground water in Stutsman County. The low estimate, compared with larger irrigable land and water supply estimates, is due to poor spatial correspondence between water supplies and irrigable land. In many cases, the good water is not located near the irrigable land.

Of 6,063 acres permitted for irrigation using surface water, about 5,465 is accounted for by total acreage allocated for irrigation using 2,100 acre-feet of effluent from waste ponds from Latish Malting Company. However, the original source of this water was the Spiritwood aquifer. Of the remaining acreage, about 250 acres would be accounted for by a reliable source (the James River) and the remaining portion would be from other surface-water sources, which would not be reliable in mid or late summer. Irrigation from surface-water sources is thus insubstantial in Stutsman County. Substantial increased irrigation from surface-water sources in Stutsman County would not be likely.

Total potential irrigation development for Stutsman County is estimated at about 7,000 acres. As many as 3,000 additional acres may be irrigable from the Spiritwood aquifer. However, such additional development would have to be approached with caution.

POTENTIAL IRRIGATION DEVELOPMENT IN STUTSMAN COUNTY NORTH DAKOTA

The purpose of this report (chapter) is to provide an evaluation of land and water available for potential irrigation development in Stutsman County. Methods of assessment used in this report were designed to provide a conservative estimate. These methods were described in a previous introductory section. It is emphasized that the findings of this report are based on general information. They are preliminary, and they should not be used for individual project planning without further local in-depth analysis. For the sake of continuity in computation, data on computation tables are provided to the nearest digit. However, this should not lead to the conclusion that this report can estimate acreage with such a high level of precision. **In the text of this report, the final summary estimates resulting from table computations are rounded to the nearest 500 acres.** These final rounded numbers reflect more appropriately the general character of these estimates.

Current Irrigation Development

In Stutsman County there are currently 38 irrigation permits for the irrigation of 10,739 acres. However, of this total only 7,374 acres can be irrigated in any given year. The description of water permits in Stutsman County is complicated somewhat by water use of Ladish Malting Company. Ladish malt holds an industrial permit for 2,680 acre feet from the Spiritwood aquifer. About 93% of the water used by Ladish Malting Co. is non consumptive and is available for irrigation from storage ponds after use. Ladish Malting Co. also holds a water permit which allow the irrigation of 5,400 gross acres using 2,100 acre-feet of water from the effluent ponds. The number of acres actually irrigated annually is considerably less, however. In 1992 about 1,776 acre-feet of water were actually pumped from the Spiritwood aquifer for industrial use. In 1993 total water pumped from the Spiritwood aquifer by Ladish Malting Co. for industrial use (from five wells) was 1,821 acre feet.

In relation to the goals of this summary, the simplest net description of the Ladish Malting Co. permits would be to treat them as an approximate 2,000 acres of annual irrigation water use from the Spiritwood aquifer. Using this simplification, equivalent irrigation permits would be about 6,776 acres of annual irrigation using ground water, and about 663 acres of annual irrigation using water from the James River and other surface-water sources. Actual annual use of water for irrigation between 1991 and 1993 varied from a minimum of 955 acres in 1993, to a maximum of 6,212 acres in 1992.

IRRIGATION DEVELOPMENT FROM GROUND WATER

Assessment of potential irrigable land in this report will not be limited to or based on actual current water permits, or on current actual irrigated acreage. Rather it will be based on evaluation of the water and soil resource. In Stutsman County twenty aquifers have been identified as potential water sources for irrigation. These are listed on Table 1. There are two possible limiting factors affecting potential irrigation development using ground water. These are (1) irrigable land within practical distance of the water source , and (2) available water of suitable quality in close proximity to irrigable land.

Total Irrigable Soils

There are approximately 1,441,270 acres in Stutsman County. According to a study conducted by North Dakota State University (NDSU) there are about 1,182,000 acres of irrigable and conditionally irrigable land in Stutsman County (Omodt, written communication, 1982). Of this most, about 91 %, is classified as conditionally irrigable because of slope, drainage requirements, or slowness of internal drainage.

The classification used in this report is a much more restrictive subset of that used in the NDSU study. A soil association map (USDA-SCS, unpublished 1995) is provided on Figure St-1. All soils requiring extensive surface or internal drainage are excluded from consideration, and all soils having slopes of more than 3 % are also excluded. Using the criteria of this study, most of western Stutsman county is classified as non irrigable and most of eastern Stutsman county is classified as conditionally irrigable. Non irrigable classification in western Stutsman County is largely due to the steeper topography of the Missouri Coteau, and the wetlands formed within the depressional areas of the Coteau. About 64,170 acres are classified as Group 1 (irrigable without limitations, slope less than 3 %) soils based on Stutsman County SCS soil survey tabulations. There are an additional 57,480 irrigable acres in the Group 2 category (irrigable with limitations). Usually the limitation is fineness of soil, which requires limited rates of water application, or the need for internal or surface drainage. Thus, based on soil suitability alone, there are about 121,650 acres of potentially irrigable land. A map of soil Groups (irrigable, conditionally irrigable, and non irrigable) as defined for this study is provided on Figure St-2.

All federal, state, and municipal land is excluded from the estimate of potentially irrigable acres. There are about 68,075 acres of state and federal land, and about 34,560 acres of municipal land, for a total of about 102,635 acres of government land. About 8 % of all land in Stutsman County is classified as irrigable according to standards of this study. Applying this proportion to government land gives 8,211 acres of excluded land that might be considered irrigable. After subtracting

Table 1. Resources for potential irrigation development in Stutsman County, ND. ECE is the electrical conductivity of water; SAR is the sodium adsorption ratio of water; and Boron is the concentration of boron in water. Potential irrigable acres based on water limitations (column 8) are calculated by multiplying the total acreage (column 7) by the recharge coefficient coefficient in column (6) as described in the text, and by adjusting for water quality (column 5). Land mapped in irrigable soils series, and having a slope of less than 3% (column 10) is calculated from land area mapped in irrigable associations overlying the aquifer (column 9), adjusted for the proportion of the association attributed to soils of irrigation suitable series, and by an adjustment factor (0.43) accounting for slopes greater than 3%. The final estimate of potential irrigation development (column 11), is half of column 10. **Bold type** indicates most limiting estimate of potential irrigation, used in final estimates of potential irrigation development. (c) means aquifer is confined with less than 50 feet of overburdon. (c†) means that aquifer is deeply confined, having more than 50 feet of overburdon. (u) means that aquifer is unconfined. (c/u) or (u/c) means that aquifer is variably confined and unconfined.

(1) WATER SOURCE	(2) ECE %<1500 µS/cm	(3) SAR %< 6	(4) BORON %<2 mg/L	(5) WATER QUALITY COEFFICIENT	(6) RECHARGE COEFFICIENT	(7) AREA OVERLYING AQUIFER acres	(8) POTENTIAL IRRIGABLE ACRES-WATER LIMIT acres	(9) LAND MAPPED IN IRRIGABLE ASSOCIATIONS acres	(10) LAND MAPPED IN IRRIGABLE SOIL SERIES, SLOPE < 3% acres	(11) POTENTIAL IRRIGABLE SOIL OVERLYING AQUIFER acres
Courtenay -c	-	-	-	0.5**	0.1	678	33	678	133	66
Deer Creek -c†	-	-	-	0.5**	0.04	9,638	192	0	0	**0**
Eric Lake c†	-	-	-	0.5**	0.04	8,243	164	0	0	**0**
Homer c†	-	-	-	0.5**	0.1	8,806	**440**	88,06	2,905	1,452
Goldwin c/u	-	-	-	0.5**	0.2	8,192	819	0	0	**0**
Jamestown -c†	50	100	100	1	0.1	7,161	**716**	71,61	2,362	1,181
Klose -c	-	-	-	0.5	0.1	4,281	**214**	33,21	657	328
Marstonmoor Plain u	100	100	100	1	0.33	30,105	9,934	0	0	**0**
Medina c/u	-	-	-	0.5	0.2	4,358	435	0	0	**0**
Midway -c†	100	60	100	0.6	0.04	29,209	**701 / 632 ††**	29,209	10,602	5,301

* Sparse data.
** Insufficient data. Water quality coefficient based on other nearby aquifers.
†† Adjusted for overlap of aquifers. Montpelier aquifer overlies Spiritwood aquifer, and Seven-Mile Coulee aquifer overlies Midway aquifer. Recharge computations are allocated to the upper aquifer, and recharge area is excluded from computations of recharge for the lower aquifer.

Table 1. (Cont). Resources for potential irrigation development in Stutsman County, ND. ECE is the electrical conductivity of water; SAR is the sodium adsorption ratio of water; and Boron is the concentration of boron in water. Potential irrigable acres based on water limitations (column 8) are calculated by multiplying the total acreage (column 7) by the recharge coefficient coefficient in column (6) as described in the text, and by adjusting for water quality (column 5). Land mapped in irrigable soils series, and having a slope of less than 3% (column 10) is calculated from land area mapped in irrigable associations overlying the aquifer (column 9), adjusted for the proportion of the association attributed to soils of irrigation suitable series, and by an adjustment factor (0.43) accounting for slopes greater than 3%. The final estimate of potential irrigation development (column 11), is half of column 10. **Bold type** indicates most limiting estimate of potential irrigation, used in final estimates of potential irrigation development. (c) means aquifer is confined with less than 50 feet of overburdon. (c†) means that aquifer is deeply confined, having more than 50 feet of overburdon. (u) means that aquifer is unconfined. (c/u) or (u/c) means that aquifer is variably confined and unconfined.

(1) WATER SOURCE	(2) ECE %<1500 µS/cm	(3) SAR %< 6	(4) BORON %<2 mg/L	(5) WATER QUALITY COEFFICIENT	(6) RECHARGE COEFFICIENT	(7) AREA OVERLYING AQUIFER acres	(8) POTENTIAL IRRIGABLE ACRES-WATER LIMIT acres	(9) LAND MAPPED IN IRRIGABLE ASSOCIATIONS acres	(10) LAND MAPPED IN IRRIGABLE SOIL SERIES, SLOPE < 3% acres	(11) POTENTIAL IRRIGABLE SOIL OVERLYING AQUIFER acres
Montpelier c	-	-	-	0.5	0.1	14,278	**713**	14,278	6,124	3,062
Mt. Moriah -c†	-	-	-	0.5	0.04	1,395	27	0	0	0
Plainview	-	-	-	0.5	0.04	1235	24	1,235	366	183
Seven Mile Coulee c/u	90	100	100	1	0.2	2,867	573	2,867	849	**424**
Spiritwood -c† (North/Rose and Spiritwood Townships)	90	50	98	0.5	-	32,576	**2,000**	78,656	33,743	16,871
Spiritwood -c† (South / Winfield and Ypsilanti Townships)	90	50	98	0.5	0.04	46,080 / 31,802	922 / **636** ††			
Streeter	95	85	99	0.85	0.1	466	39	0	0	**0**
Sydney -c†	-	-	-	0.5	0.04	1,728	34	1,728	741	370
Upper Buffalo Creek -c†	-	-	-	0.5	0.04	4,096	81	4,096	1,351	675
Ypsilanti c/u	75	100	75	0.75*	0.2	5,305	**795**	5,305	1,750	875
Windsor -c†	-	-	-	0.5	0.04	9,024	**180**	5,024	1,325	662
Total						229,721	18,681	162,364	62,915	31,457

* Sparse data.
** Insufficient data. Water quality coefficient based on other nearby aquifers.
†† Adjusted for overlap of aquifers. Montpelier aquifer overlies Spiritwood aquifer, and Seven-Mile Coulee aquifer overlies Midway aquifer. Recharge computations are allocated to the upper aquifer, and recharge area is excluded from computations of recharge for the lower aquifer.

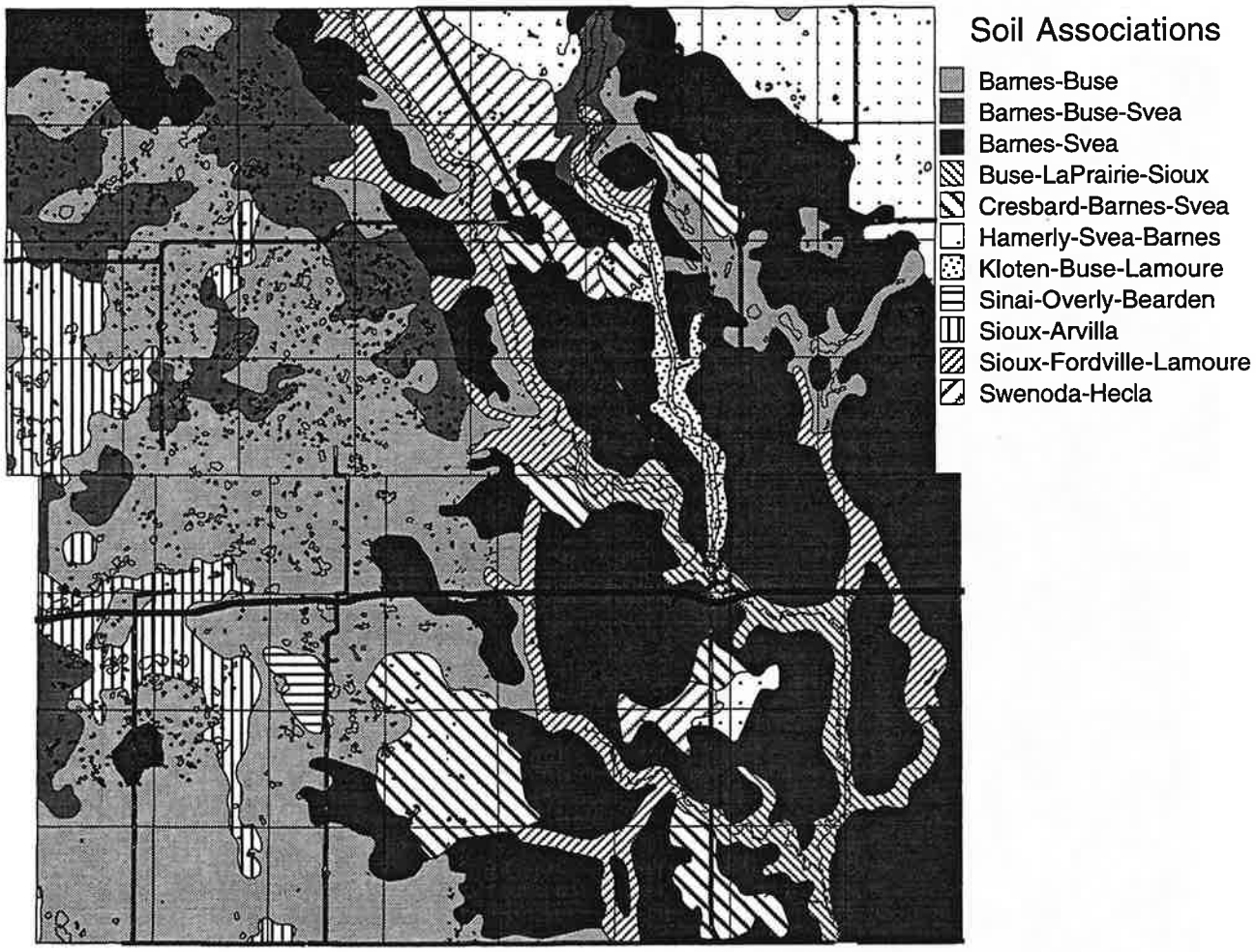

Figure St-1. Soil association map of Stutsman County ND. (From Stutsman County Soil Survey, USDA-SCS , unpublished, 1995).

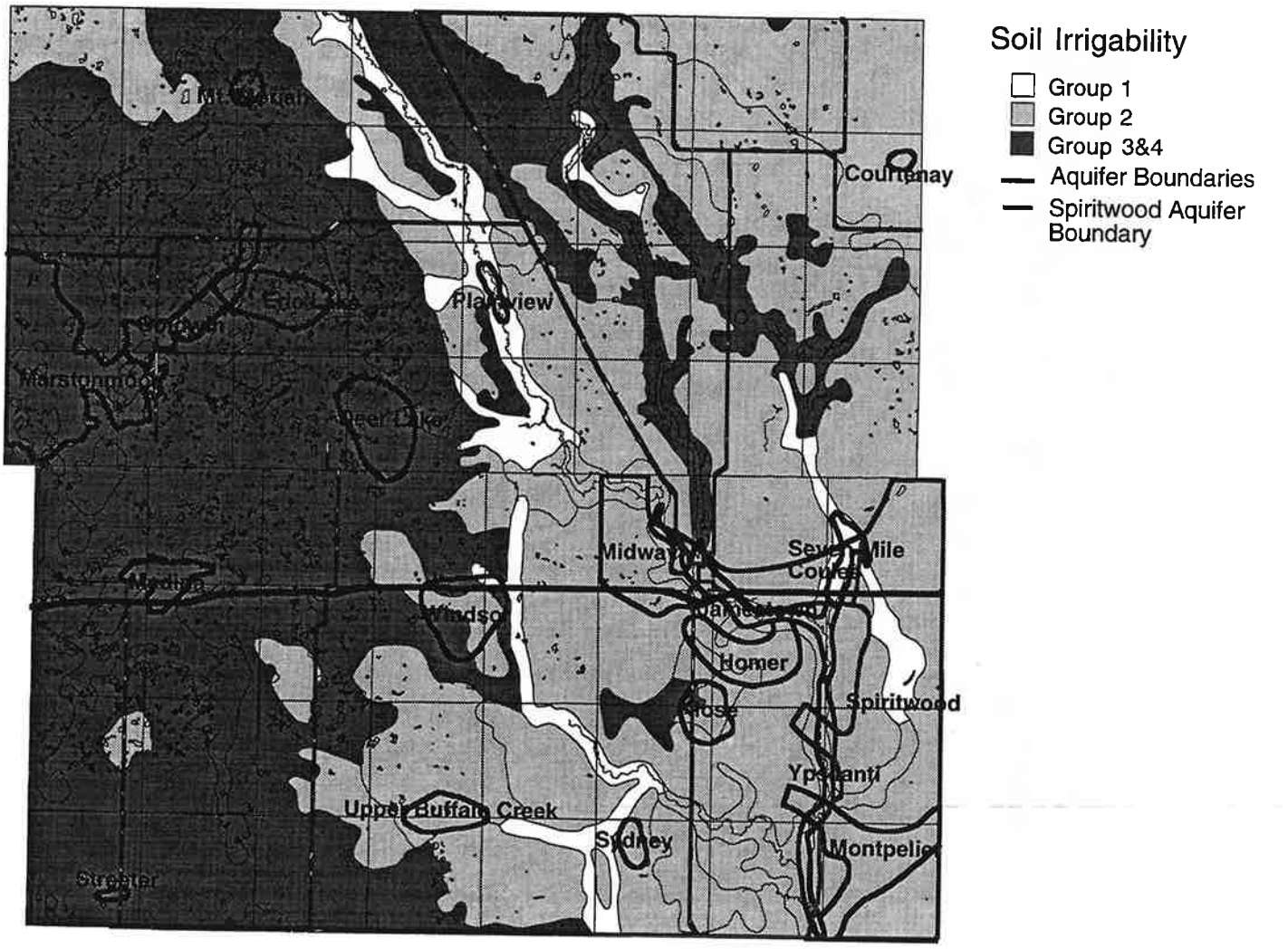

Figure St-2. Map of boundaries of the principal aquifers in Stutsman County, ND. (From Huxel and Petri, 1965).

estimated irrigable government land, approximately **113,500** (113,439) **acres would be considered to be potentially irrigable based on soil factors alone.**

Estimates of Irrigable Soil Overlying Aquifers

The overall estimates of irrigable soils discussed above were taken from soil survey summary tables and were adjusted for slopes greater than 3%. Estimates of irrigation-suitable soil overlying aquifers were calculated by integrating the areas of mapped soil associations within mapped aquifer boundaries. Area mapped to soil associations considered to be predominantly irrigable were adjusted by the percent of soil series within the association considered to be irrigable. In addition, irrigable series were adjusted to account for slopes greater than 3% using a factor of 0.66. Stutsman County soil summary table data indicated that about 66 % of soils mapped in series considered irrigable, had slopes of less than 3 %. Finally, a 1/2 contingency factor was applied to all estimates of irrigable soil area. Results in Table 1, column 11 indicated that **about 31,500 acres** (31,457 acres) **of land overlying aquifers would be considered as potentially irrigable based on soil suitability alone.**

Irrigable Land Overlying Aquifers Based on Water Supply Limitations

Ground-water resources in Stutsman County have variable quality for irrigation use. Between 50 and 100 % of the ground water from aquifers considered on Table 1 are of suitable quality for irrigation. Water quality is evaluated on the basis of suitable electrical conductivity (ECE), sodium adsorption ratio (SAR), and Boron concentration (Table 1).

Estimates of water available for potential irrigation are based on an estimated recharge 0.3 inches per year for deeper confined aquifers in glacial till, 1.2 inch per year for shallow confined aquifers, 2.5 inches per year for aquifers that are partly confined, and partly unconfined, and 4 inches per year for unconfined aquifers. The recharge coefficient is the estimated recharge divided by the 12-inch use estimate. Recharge coefficients calculated for 0.3, 1.2, 2.5, and 4 inches are 0.025, 0.1, 0.21, and 0.33, respectively. In some cases, depending on the aquifer, ranges of values between these coefficients are selected. Many of the aquifers in Stutsman County are deeply buried in the glacial till. Some aquifers overlap others. For example, the Seven-Mile Coulee aquifer overlies the Spiritwood aquifer, and the Montpelier aquifer overlies the Midway aquifer. Since both aquifers in each case occupy the same recharge area, recharge estimates are applied only to the shallowest aquifer, and the areas of the deeper aquifers are excluded from the computations.

Irrigation acreage based on sustainable water use is further adjusted by the water quality coefficient, which is the probability of obtaining water suitable for irrigation at a given location (Table 1,

column 5). The most limiting parameter (of ECE, SAR, Boron) is used to adjust for water quality. The resulting irrigable acreage estimate based on recharge and water quality is in Table 1, column (8).

Because of additional information available for part of the Spiritwood aquifer, the Spiritwood aquifer is given some further consideration. Sustainable yield from the Spiritwood aquifer is generally computed based on an estimated recharge of about 0.5 inches per year. In some parts of the Spiritwood aquifer, this would be considered high. However, there are certainly areas where the Spiritwood has better connection to the surface, and significantly larger recharge. There is insufficient information to deal with such local heterogeneities on a more detailed level, so the estimate of 0.5 must suffice for this report. However, it is known that Ladish Malting Co. is currently pumping about 1,800 acre-feet per year from the Spiritwood aquifer at one location. Despite the localized concentration of pumping, piezometric levels in the Spiritwood aquifer near Ladish Malting Co. appears have been holding at a steady level. Most of this water can be used for irrigation. It appears likely that sustainable yield exceeds the 0.5 inch recharge estimate in the vicinity of Ladish Malting Co.

For purpose of analysis, the Spiritwood aquifer in Stutsman County is divided into two components, which are treated separately. The first component consists of Spiritwood and Winfield townships. The Ladish Malting Co. wells are located within this unit. It is assumed that the Ladish Malting Co. permit for 2,680 acre feet may fully allocate the water available from the Spiritwood aquifer in these two townships, and that about 2,000 acre-feet of this could be used for irrigation, after use in the malting facility.

The second component consists of the southernmost two townships (Ypsilanti and Manns) overlying the Spiritwood aquifer. The area of the aquifer underlying the second component (about 46,080 acres) is used to compute sustainable yield using the 0.5 inch per year recharge value described previously. Sustainable yields for portions of the Spiritwood underlying the shallower Montpelier aquifer are computed using the higher estimated recharge (1.2 inch per year) for the Montpelier aquifer. Results indicate that about 636 additional acres could possibly be irrigated from the Spiritwood aquifer in the southern two townships in Stutsman County. Adding the 713 acres of potential development for the Montpelier aquifer, results in a total estimate of 1,300 acres of irrigation development from the Spiritwood aquifer, apart from the Ladish Malting Co. water permit.

Potential Irrigation Development from Ground Water in Stutsman County

The most limiting factor in Table 1 [water limiting (column 8); or soil limiting (column 11)] is used to estimate potential irrigation development from ground water in Stutsman County. Parcels of land less than 130 acres are not included in the sum of potentially irrigable acres. **The sum of potentially irrigable acres based on the most limiting resource is about 7,000 acres** (6,819 acres). This total includes irrigation of 2,000 acres using effluent from Ladish Malting Co.

Because there are already 6,776 acres of irrigation permitted from ground water in Stutsman County (including the approximate 2,000 acres irrigated using effluent water from Ladish Malting Co.), it might be concluded that potential for increased irrigation in Stutsman County is limited.

The discrepancy between the large estimates of available land and available water for irrigation, and the relatively low estimate of irrigation development potential is largely due to the poor correspondence between irrigable soil and water resources in Stutsman County. The entire western portion of Stutsman County consists of high and rolling terrain on the Missouri Coteau. Some of the most promising potential water sources are located in this area. Water supplies for irrigation of about 11,500 acres are estimated for the Deer Creek, Eric Lake, Goldwin, Marstonmoor Plain, Medina, Mount Moriah, and Streeter aquifers. Each of these have corresponding estimates of no irrigable soils (Figure St-2 and Table 1). The Marstonmoor Plain aquifer alone, is estimated to have water of excellent quality in sufficient quantities to irrigate about 10,000 acres. However, it is located in an area of generally steep topography.

Additional Comments

While estimates based on sustainable yield would indicate that potential for irrigation development is limited, some additional irrigation may be allowable from limited mining of large aquifers, like the Spiritwood. It is estimated that up to 3,000 acres might be irrigable for many years from the Spiritwood aquifer in Stutsman County, allowing for mining of about 10% of current storage.

Also, a very large amount of good quality water, particularly in the Marstonmoor Plain aquifer, has been excluded from potential development because of the steep and otherwise unsuitable overlying soil based on soil association maps. Soil associations maps are of broad scale, and there remains the likelihood of limited development on localized soils that are suitable for irrigation. Such development would likely occur as small isolated tracts. Smaller field sizes than the common quarter-section center pivot tract would be likely in many cases. Such development would have to be pursued on the basis of more detailed local studies than this report can provide.

IRRIGATION DEVELOPMENT USING SURFACE WATER

Surface water sources in Stutsman County include the James River and Pipestem Creek, and tributaries. Of 6,063 acres approved for irrigation using surface water, 5,400 acres are permitted for ponded effluent from the Ladish Malting Co. facility, that actually originates in the Spiritwood aquifer. The Ladish Malting Co. effluent has already been considered as ground water. Actual irrigation from non effluent surface-water sources totals about 600 acres. Of the current water permits, only 242

acres are permitted for irrigation using water from the James River main stem. There is no irrigation using waters removed directly from the main stem of Pipestem Creek. The additional irrigation (about 422 acres) is from non main stem tributaries and sloughs. These would not likely be dependable sources. Moreover, both the James River and Pipestem Creek are heavily appropriated. Further issuance of water permits for these sources is not likely. On this basis, **a total of about 250 acres are considered to be irrigable from surface water in Stutsman County.**

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT

A total of 7,000 to 7,500 acres are considered to be irrigable from combined ground water and surface water sources in Stutsman County. This total is close to current appropriations. As many as 3,000 additional acres might be irrigated for a substantial period of time from limited mining of water in the Spiritwood aquifer. This, however, would have to be carefully evaluated. There may also be further potential irrigation in the western portion of Stutsman County, particularly in the area of the Marstonmoor Plain aquifer. Such additional irrigation would likely be in small tracts.

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Potential Irrigation Development in Wells County, North Dakota

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT FOR WELLS COUNTY

About 24,000 acres overlying aquifers in Wells County have soils classified as irrigable or conditionally irrigable, have slopes of less than 3 %, are free from substantial surface and subsurface drainage requirements, and lie in parcels of sufficient size for irrigation. In this study, estimates of potentially irrigable land are based on total land classified as irrigable, multiplied by a contingency factor of 1/2 to account for potential error, and land owner preferences regarding development. The contingency factor is also intended to lend a conservative bias to this report. Application of the contingency factor results in an estimate of at least 12,000 acres of irrigable land in Wells County.

Water quality for irrigation is variable. Percent of water in each aquifer having water quality suitable for irrigation variies from 50% to 100%. Most aquifers had suitable quality for irrigation in only 50 to 60% of the samples. Estimates of long-term sustainable yield indicate that sufficient water for about 6,500 acres of irrigation is possible on a long-term basis.

Potential irrigation development is estimated by summing the most limiting resource (irrigable land or water) for each aquifer. **Results indicate that development of about 6,000 acres for irrigation should be feasible in Wells County.** However, there may be some difficulty in locating specific sites suitable for irrigation, because of variability in water quality. Irrigation from surface water is insubstantial, and does not add to the overall amount of potential irrigation. Estimates of potential irrigation development in this report compare with a total of 791 acres currently permitted for irrigation in Wells County.

POTENTIAL IRRIGATION DEVELOPMENT IN WELLS COUNTY NORTH DAKOTA

The purpose of this report (chapter) is to provide an evaluation of land and water available for potential irrigation development in Wells County. Methods of assessment used in this report were designed to provide a conservative estimate. These methods were described in a previous introductory section. It is emphasized that the findings of this report are based on general information. They are preliminary, and they should not be used for individual project planning without further local in-depth analysis. For the sake of continuity in computation, data on computation tables are provided to the nearest digit. However, this should not lead to the conclusion that this report can estimate acreage with such a high level of precision. **In the text of this report, the final summary estimates resulting from table computations are rounded to the nearest 500 acres.** These final rounded numbers reflect more appropriately the general character of these estimates.

Current Irrigation Water Permits and Water Use

In Wells County there are currently only five irrigation permits for a total of 791 acres. Annual use averages less than half of the approved acreage. Between 1991 and 1993 largest irrigated acreage was 390 in 1992. Least irrigation (60 acres) occurred in 1993, which was an extremely wet year. In most years it is likely that nearly 300 acres are irrigated.

IRRIGATION DEVELOPMENT FROM GROUND WATER

In Wells County, there are currently 392 acres permitted for irrigation using ground water. However, actual annual irrigation from 1991 through 1993 varied from as little as 60 acres to as much as 230 acres. Assessment of potential irrigable land in this report will not be limited to or based on actual current water permits, or on current actual irrigated acreage. Rather it will be based on evaluation of the water and soil resource. In Wells County four aquifers have been identified as potential sources for irrigation. These are listed on Table 1. There are two possible limiting factors affecting potential irrigation development using ground water. These are (1) irrigable land within practical distance of the water source , and (2) available water of suitable quality in close proximity to irrigable land.

Total Irrigable Soils

There are approximately 820,051 acres in Wells County. According to a study conducted by North Dakota State University (NDSU) there are about 643,355 acres of irrigable and conditionally

Table 1. Resources for potential irrigation development in Wells County, ND. ECE is the electrical conductivity of water; SAR is the sodium adsorption ratio of water; and Boron is the concentration of boron in water. Potential irrigable acres based on water limitations (column 8) are calculated by multiplying the total acreage (column 7) by the recharge coefficient coefficient in column (6) as described in the text, and by adjusting for water quality (column 5). Land mapped in irrigable soils series, and having a slope of less than 3% (column 10) is calculated from land area mapped in irrigable associations overlying the aquifer (column 9), adjusted for the proportion of the association attributed to soils of irrigation suitable series, and by an adjustment factor (0.60) accounting for slopes greater than 3%. The final estimate of potential irrigation development is half of column 10. **Bold type** indicates most limiting estimate of potential irrigation, used in final estimates of potential irrigation development. (c) means aquifer is confined with less than 50 feet of overburdon. (c†) means that aquifer is deeply confined, having more than 50 feet of overburdon. (u) means that aquifer is unconfined. (c/u) means that aquifer is variably confined and unconfined.

(1) WATER SOURCE	(2) ECE %<1500 µS/cm	(3) SAR %< 6	(4) BORON %<2 mg/L	(5) WATER QUALITY COEFFICIENT	(6) RECHARGE COEFFICIENT	(7) AREA OVERLYING AQUIFER acres	(8) POTENTIAL IRRIGABLE ACRES-WATER LIMIT acres	(9) LAND MAPPED IN IRRIGABLE ASSOCIATIONS acres	(10) LAND MAPPED IN IRRIGABLE SOIL SERIES, SLOPE < 3% acres	(11) POTENTIAL IRRIGABLE SOIL OVERLYING AQUIFER acres
Carrington -c	100	100	100	1.0	0.1	5,625	**562**	5,625	2,295	1,147
Heimdal -u	60	100	100	0.6	0.33	6,995	**1,385**	6,835	2,665	1,333
Manfred -c/u	60	60	100	0.6	0.21	10,496	**1,322**	10,496	2,833	1,416
Martin -c	60	60	100	0.6	0.1					
New Rockford -c†	55	50	100	0.5	0.05	41,510*** / 39,100	**977**	39,750 / 38,469!	10,413	5,207
Pipestem * -u	-	-	-	0.5	0.33	6,528	**1,077**	6,368	2,483	1,241
Rocky Run * -u	-	-	-	0.5	0.33	2,988	**493**	2,668	1,120	560
Rosefield ** -c	-	-	-	0.6	0.1	1,164	**70**	1,164	475	237
Rusland * -u	-	-	-	0.5	0.33	3,187	526	3,187	860	**430**
South Fessenden * -c	-	-	-	0.5	0.1	1,024	**51**	1,024	431	215
Total	50	65	100	0.5		77,117	6,463	77,117	23,575	11,786

* No water quality data were available. Used probability of most limiting case.

irrigable land in Wells County (Omodt, written communication, 1982). About 88 % is classified as conditionally irrigable because of slope, drainage requirements, or slowness of internal drainage.

The classification used in this report is a much more restrictive subset of that used in the NDSU study. A soil association map (USDA-SCS, 1970) is provided on Figure We-1. All soils requiring extensive surface or internal drainage are excluded from consideration, and all soils having slopes of more than 3 % are also excluded. Using the criteria of this study, about 149,920 acres are classified as Group 1 (irrigable without limitations, slope less than 3 %) soils based on Wells County SCS soil survey tabulations. There are an additional 90,154 irrigable acres in the Group 2 category (irrigable with limitations). Usually the limitation is fineness of soil, which requires limited rates of water application. Soils requiring extensive surface or subsurface drainage are considered as non irrigable in this study. Thus, based on soil suitability alone, there are about 270,074 acres of potentially irrigable land.

All federal, state, and municipal land is excluded from the potentially irrigable acres, except for state school lands of which 50% are excluded. Estimates of federal and state lands are approximately 23,271 acres, and town lands are estimated at 8,320. The total of excluded land is 31,591 acres. About 32 % of all land in Wells County is classified as irrigable according to standards of this study. Applying this proportion to government land gives 10,404 acres of excluded land that might be considered irrigable. After subtracting estimated irrigable government land, approximately **260,000** (259,669) **acres would be considered to be potentially irrigable based on soil factors alone.** A map of soil Groups (irrigable, conditionally irrigable, and non irrigable) as defined for this study is provided on Figure We-2.

Estimates of Irrigable Soil Overlying Aquifers

The overall estimates of irrigable soils discussed above were taken from soil survey summary tables and were adjusted for slopes greater than 3%. Estimates of irrigation-suitable soil overlying aquifers were calculated by integrating the areas of mapped soil associations within mapped aquifer boundaries. Area mapped to soil associations considered to be predominantly irrigable were adjusted by the percent of soil series within the association considered to be irrigable. In addition, irrigable series were adjusted to account for slopes greater than 3% using a factor of 0.6. Wells County soil summary table data indicated that about 60 % of soils mapped in series considered irrigable, had slopes of less than 3 %. Finally, a 1/2 contingency factor was applied to all estimates of irrigable soil area. Results in Table 1, column 11 indicated that **about 12,000 acres** (11,7836 acres) **of land overlying aquifers would be considered as potentially irrigable based on soil suitability alone.**

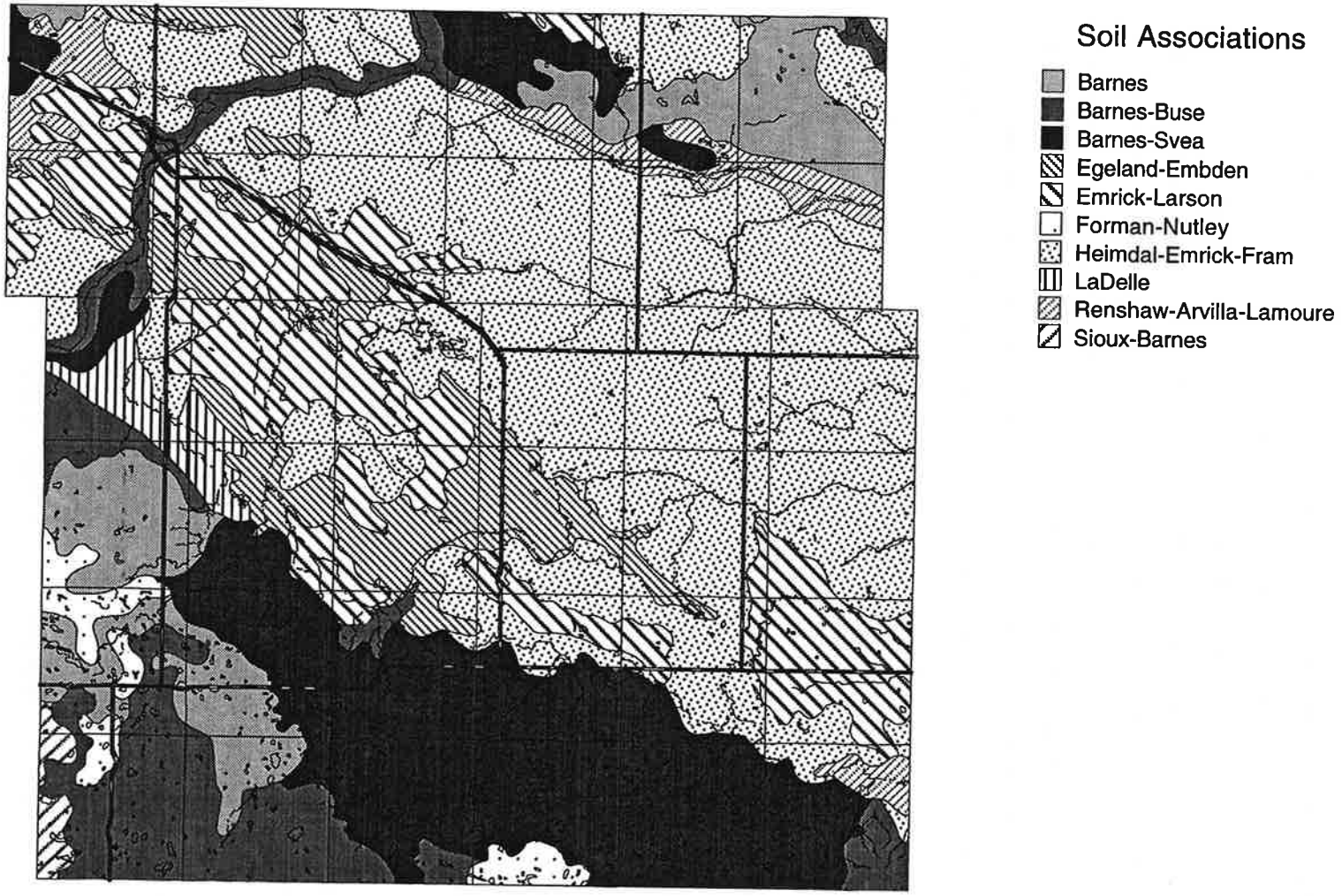

Figure We-1. Soil association map of Wells County ND. (From Wells County Soil Survey, USDA-SCS , 1970).

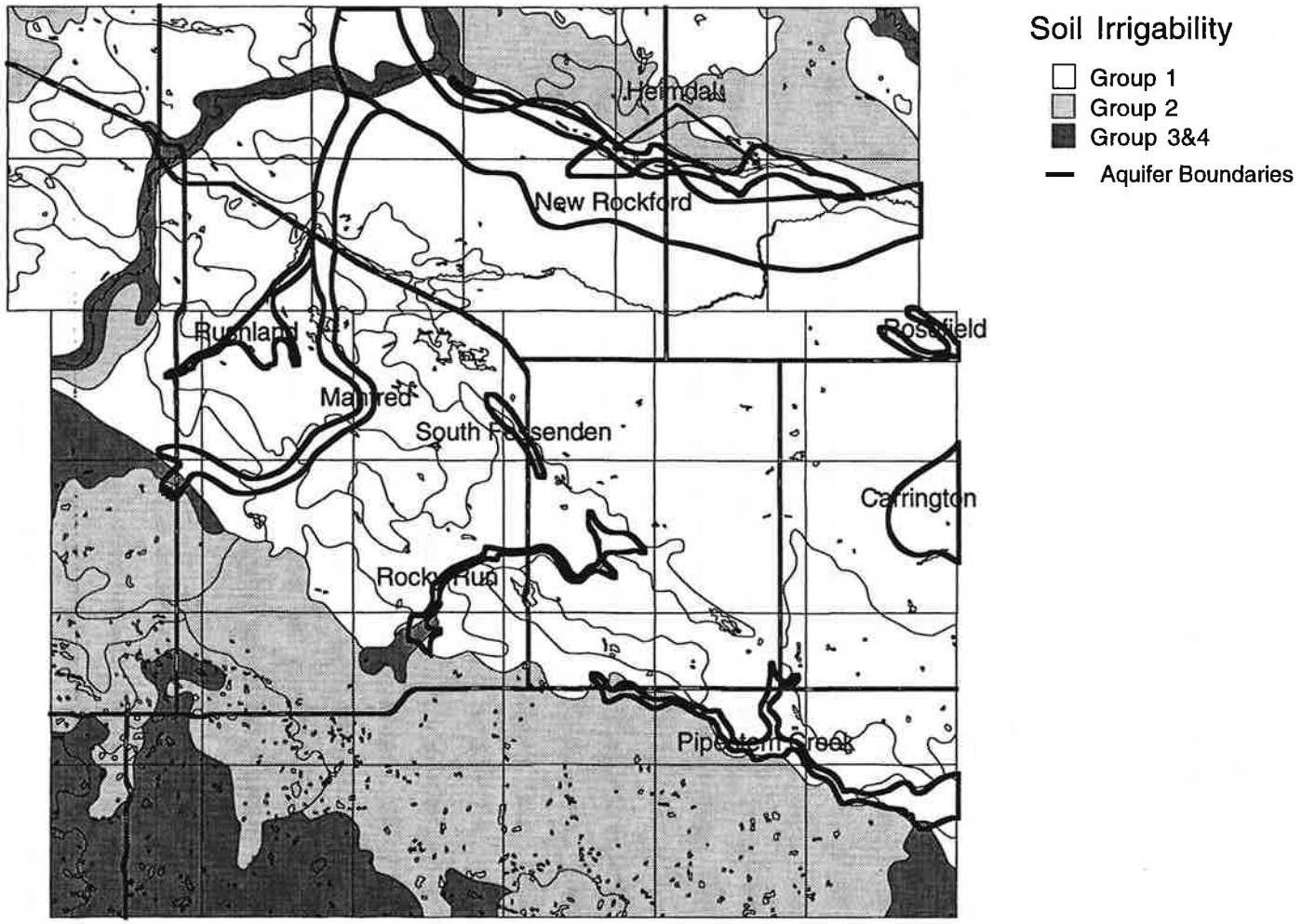

Figure We-2. Map of boundaries of the principal aquifers in WellsCounty, ND. (From Buburla, 1970).

Irrigable Land Overlying Aquifers Based on Water Supply Limitations

Ground-water resources in Wells County have variable quality for irrigation use. Between 50 and 100 % of the ground water from aquifers considered on Table 1 are of suitable quality for irrigation. Water quality is evaluated on the basis of suitable electrical conductivity (ECE), sodium adsorption ratio (SAR), and Boron concentration (Table 1). Estimates of water available for potential irrigation are based on an estimated recharge of 0.3 inches per year for deeper confined aquifers in glacial till, 1.2 inch per year for shallow confined aquifers, 2.5 inches per year for aquifers that are partly confined, and partly unconfined, and 4 inches per year for unconfined aquifers. Irrigable acreage for each aquifer is then calculated by assuming an average of 12 inches per acre per year irrigation. The recharge coefficient is the estimated recharge divided by the 12-inch use estimate. Recharge coefficients calculated for 0.3, 1.2, 2.5, and 4 inches are 0.025, 0.1, 0.21, and 0.33, respectively.

While such simplified discrete numbers can be applied in some circumstances, many aquifers are comprised of highly complex systems of coarse deposits, varying from deeply buried to surficial positions. Results must also consider variations in the overlying till, and the possibility of connection between stratified deposits. In Wells County, the Carrington, Martin, New Rockford, and Rosefield aquifers are confined. However, overlying glacial drift is frequently coarse. The New Rockford aquifer is deeply buried, and is overlain in parts by the Heimdal aquifer. The Heimdal, Manfred, Pipestem, Rocky Run, and Rusland aquifers were formed either as outwash, or as meltwater channels and are generally unconfined, or partially unconfined. Recharge coefficients selected for each of these aquifers are shown on Table 1, column 6.

Irrigation acreage based on sustainable water use is further adjusted by the water quality coefficient, which is the probability of obtaining water suitable for irrigation in a given well (Table 1, column 5). The most limiting parameter (of ECE, SAR, Boron) is used to adjust for water quality. The resulting irrigable acreage estimate based on recharge and water quality is in Table 1, column 8. **About 6,500 acres are estimated as potentially irrigable, based on estimates of available water of suitable quality for irrigation.**

Potential Irrigation Development from Ground Water in Wells County

The most limiting factor in Table 1 [water limiting (column 8); or soil limiting (column 11)] is used to estimate potential irrigation development from ground water in Wells County. Water is most limiting for all aquifers but the Rusland. Based on Table 1, **about 6,000 acres** (6,246 acres) **are estimated as having potential for irrigation development in Wells County.** The estimated potential development of 6,000 acres compares with an actual current ground water permit allocation of 392 acres for irrigation, and actual current annual water use of close to 300 acres.

Additional Comments

It is the sense of the managing hydrologist for Wells County (Jon Patch, personal communication, March 1995) that the 6,500-acre estimate may be on the "upper" rather than "lower" end of a realistic assessment of irrigation potential for Wells County. Mr. Patch has indicated concern over the water quality limitations. While the water quality factor used in this report should account for this limitation in total development, there still remains the problem of finding the good quality water in each aquifer. There also remains the possibility that the better quality water may be located in local concentrations which make full use and development difficult. On the other hand, estimates for potential development are based on sustainable yield for an indefinite period. A reasonable and limited level of mining might be allowable where there is large aquifer storage, and such additional use could be applied for many years in some cases. This possibility would have to be evaluated on an individual aquifer basis.

Finally, the reader is cautioned that the computation methods are general in nature, and on any given aquifer may be overly generous, or excessively limited. To a certain degree, such variances in estimation should cancel in the overall evaluation of the county. Actual irrigation potential for a given aquifer could only be determined through detailed local investigation, and through the ongoing process of assessment which occurs during the implementation of gradual irrigation development.

IRRIGATION DEVELOPMENT USING SURFACE WATER

Surface water sources in Wells County include the upper reaches of the James River and the Sheyenne River. There are currently only 399 acres of water permits from surface water sources. Of this, there was no irrigation in 1991 and 1993, and only 55 acres were irrigated in 1992. Both the James River and the Sheyenne River are heavily appropriated in the lower reaches, and it would seem unlikely that substantial amounts of water would be allocated for irrigation development in Wells County from these sources in the foreseeable future. Flow records for 1989 and 1991 indicated that August flows were near and sometimes less than 1 cfs during August. This amount is insufficient to reliably supply one quarter-section center pivot. It would seem from this that the reliable summer supply of irrigation water from surface-water sources in Wells County is too small to be considered.

SUMMARY OF POTENTIAL IRRIGATION DEVELOPMENT

Approximately 6,000 acres of potential irrigation, all from ground water, appears to be available for development in Wells County.

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Buburla, Frank Jr. 1970. Ground-water Resources of Wells County, North Dakota. County Ground-Water Studies 12, Part III. North Dakota State Water Commission. Bismarck, ND.

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