AQUIFER CAPACITY INVESTIGATIONS 1980–1986

Project 2.1

Water Resources Development Under
The Canada–Manitoba Interim Subsidiary Agreement
On Water Development
For Regional Economic Expansion and Drought Proofing

Manitoba Water Resources
Hydrotechnical Services

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SUMMARY

The Canada - Manitoba Interim Subsidiary Agreement on Water Development for Regional Economic Expansion and Drought Proofing provided funds under Project 2.1 to undertake Aquifer Capacity Studies. In view of their importance to rural water development studies were done in the Assiniboine Delta, Oak Lake, Glenora, Winkler, Elie and Miami Aquifers. The field work consisted of drilling 201 test holes, collecting 4000 soil samples for mechanical analysis, installing 97 monitoring stations, conducting single well pumping tests at 40 monitoring station sites, performing 20 pumping tests at farm irrigation well sites, contracting for and undertaking nine standard multi-day formal pumping tests, setting up and operating precipitation networks in the Assiniboine Delta and Oak Lake Aquifers, metering stream flow, cursory soil moisture measurements, and ERTS investigations of ground cover. The data obtained has largely been evaluated into aquifer parameter maps and graphs. These documents will allow digital computer model development and calibration for the Assiniboine Delta, Oak Lake and Glenora Aquifers. Further test work will likely be required in order to model the Winkler, Elie and particularly the Miami Aquifers. The standard United States Geological Survey aquifer model is being used to develop the aquifer management models.

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INTRODUCTION

The Canada - Manitoba Interim Subsidiary Agreement on Water Development for Regional Economic Expansion and Drought Proofing provided funds under Project 2.1 to carry out Aquifer Capacity Studies in the rural areas of Manitoba. Based on data that had been accumulated by the Water Resources Branch over previous shared cost agreements such as the ARDA agreement and from well drilling sources it was known that there were several significant aquifers that were suitable for local development for various purposes. In some cases considerable water development was already occurring for the purpose of irrigation. In other cases while the aquifers were small in aerial extent they provided critical water supplies. Six of these aquifers were selected for study. These were in order of priority, the Assiniboine Delta, Oak Lake, Glenora, Winkler, Elie, and Miami aquifers. The purpose of the studies was to determine the capability of the aquifers to supply water without significant deterioration in aquifer capacity or groundwater quality. Because of the nature of the soil in most of the aquifer situations specialized sampling techniques available through the PFRA were used to do most of the test drilling. As observation well locations generally coincided with the location of test holes the PFRA drills in most cases completed the test hole as an observation well.

The following report summarizes the aquifer information situation at the commencement of the project, details the studies undertaken, and describes the results. Comments are provided on the remaining deficiencies in some of the studied aquifer data compilations and on how these might be corrected in the future.

The investigations and evaluations involved in this report mostly predate the advent of the use of metric units. Therefore to make use of previous work in the most expeditious way this document has been completed in the units that the data was collected in.

ACKNOWLEDGEMENTS

Direction for the studies was provided by the Project 2.1 Advisory Committee; composed of Messrs. D.H. Pollock and M. Samp of the PFRA and Mr. V.M. Austford and Mr. L.R. Gray of Manitoba Water Resources. Direct supervision of the program by Manitoba Water Resources was through Mr. L. Gray, Head, Hydrogeology Section. The positive response of Messrs. A.F. Lukey and D.H. Pollock of the PFRA to the need for special test drilling added greatly to the understanding of the aquifers. The guidance and editorial comments of Messrs. Samp, Austford and Gray in the preparation of this report were appreciated.

During the five year investigation of the six aquifers numerous persons in the Water Resources Branch, the PFRA, the Engineering and Construction Branch, the Atmospheric Environment Service, Well Drilling Companies and the Farm Community assisted in the work; their input is gratefully acknowledged. Special thanks is given to the farm operators and other residents that observed the rain gauge networks and allowed the irrigation pumping tests to be conducted on their land. The writer is indebted to Messrs. M. Rutulis, J. Petsnik, R. Betcher, and A. Warkentin for technical discussions. Mr. J. Collier provided extensive advise on computer activities. Mr. W. Hnydiuk, groundwater technologist, undertook various segments of the field work and data analysis. Mr. R. Palka who prepared the Plates depicting the Assiniboine Delta and Oak Lake Aquifer structures and Mr. F. Rogowy who draughted most of the drawings deserve special mention for their diligence and attention to detail. Mrs. D. Morin carried out typing and provided extensive assistance in organizing, editing and revising the manuscript.

OBJECTIVE

The objective of the Project 2.1 Aquifer Capacity Investigations was to determine the parameters of the aquifers to the level required to carry out digital computer modelling of them for the purpose of providing groundwater management support.

Chapter 1

ASSINIBOINE DELTA AQUIFER

1.1 Previous Investigation

The sand deposits that form the Assiniboine Delta aquifer (ADA) have been known to geologists for about 100 years. The unit extends over some 1500 square miles between Douglas and Austin, and between Glenboro and Neepawa (Fig. 1).

In the Assiniboine Delta area a number of investigators have studied the surficial geology. Two were Johnson, 1934 and Halstead 1957. The vertical geology was first evaluated in detail during 1964 and 1965 when a test drilling program was undertaken over a large segment of the aquifer lying north of the Assiniboine River (Pederson 1968). Farm wells through this area were also inventoried. The farm wells were generally shallow sand points and very little specific hydrogeological data can be gleaned from this source. The geologic and hydrogeological information was compiled into a report (Pederson 1968). These investigations defined the general hydrogeological framework of the aquifer. As a part of the studies, several groundwater monitoring stations were established in the aquifer. In some cases these stations have operated for twenty years (Fig. 2), providing a substantial water level record for some parts of the aquifer. However the scope of the initial programs did not allow for the complete instrumentation of the aquifer to the extent required for analytical model calibration or development monitoring.

During the earlier studies one pumping test was performed in the north central portion of the aquifer. Also test data were obtained from the Shilo Canadian Forces Base and from two irrigation farms. When irrigation development commenced, data on the hydraulic characteristics of the aquifer particularly in the Shilo area where obtained from short duration production well tests. However because these tests usually only lasted for one or two hours and because the water was allowed to discharge onto the top of the unconfined aquifer the data was considered to be somewhat rudimentary and only indicative of the probable conditions. Further in this regard during 1979 several pumping tests of various length up to 48 hours were performed on irrigation wells. One of these was undertaken under the direction of the Water Resources Branch staff at the Bar-5 Ranch near Douglas. In all, six relatively reliable tests had been completed prior to the commencement of Project 2.1.

The only continuous weather station near the Assiniboine Delta aquifer area is the one located at the Brandon Airport. Several rural residents monitor the summer precipitation. Also in regard to precipitation, several standard snow survey stations were established in the northern segments of the ADA.

In the Assiniboine Delta aquifer area there were and still are surface water monitoring stations on the headwaters of Pine Creek, the middle and lower portions of Epinette Creek, the Whitemud River, and at Brandon and the PTH 34 bridge on the Assiniboine River.

1.2 Topography

Sand dunes and ravines occur adjacent to river and stream channels and along the eastern side while the central and northern portions of the ground surface over this aquifer are generally flat (Plate 1 and Fig 3). Similarly on the south side of the Assiniboine River, the area between the Tiger Hills to within a mile or two of the river is quite flat. In contrast the areas within a few miles of the Assiniboine River, Epinette, Pine, and Squirrel Creeks and various other small streams along the eastern side of the aquifer have incised valleys and dune topography where the relief can attain 100 feet. It appears that the dune activity occurred because of headward erosion lowering the water table thus changing the nature of the vegetation and the cohesiveness of the upper sand.

1.3 Geology

The Assiniboine Delta aquifer structure (Plate 2) is the result of a very large glacial river depositing sediments into a depression (Fig. 4) in the preglacial shale escarpment that extended back to the present location of Brandon. The upper sand unit is underlain by silt and silty clay that rests on glacial till. The glacial till was laid down on several Mesozoic Era shale units (Fig. 5).

The surficial expression of these sediments (Plate 2) was developed by the combination of the original deposition and consequent water and wind erosion. The large extent of clay that covers the central and northwestern segments of the aquifer is probably a residue of the delta topset beds.

The detailed features of the sand (aquifer) portion of the delta are discussed later under the section on the results of the study. However in general the sand and gravel thickness varies from a few feet along the extremities to 280 feet at one place in the northeastern part of the delta.

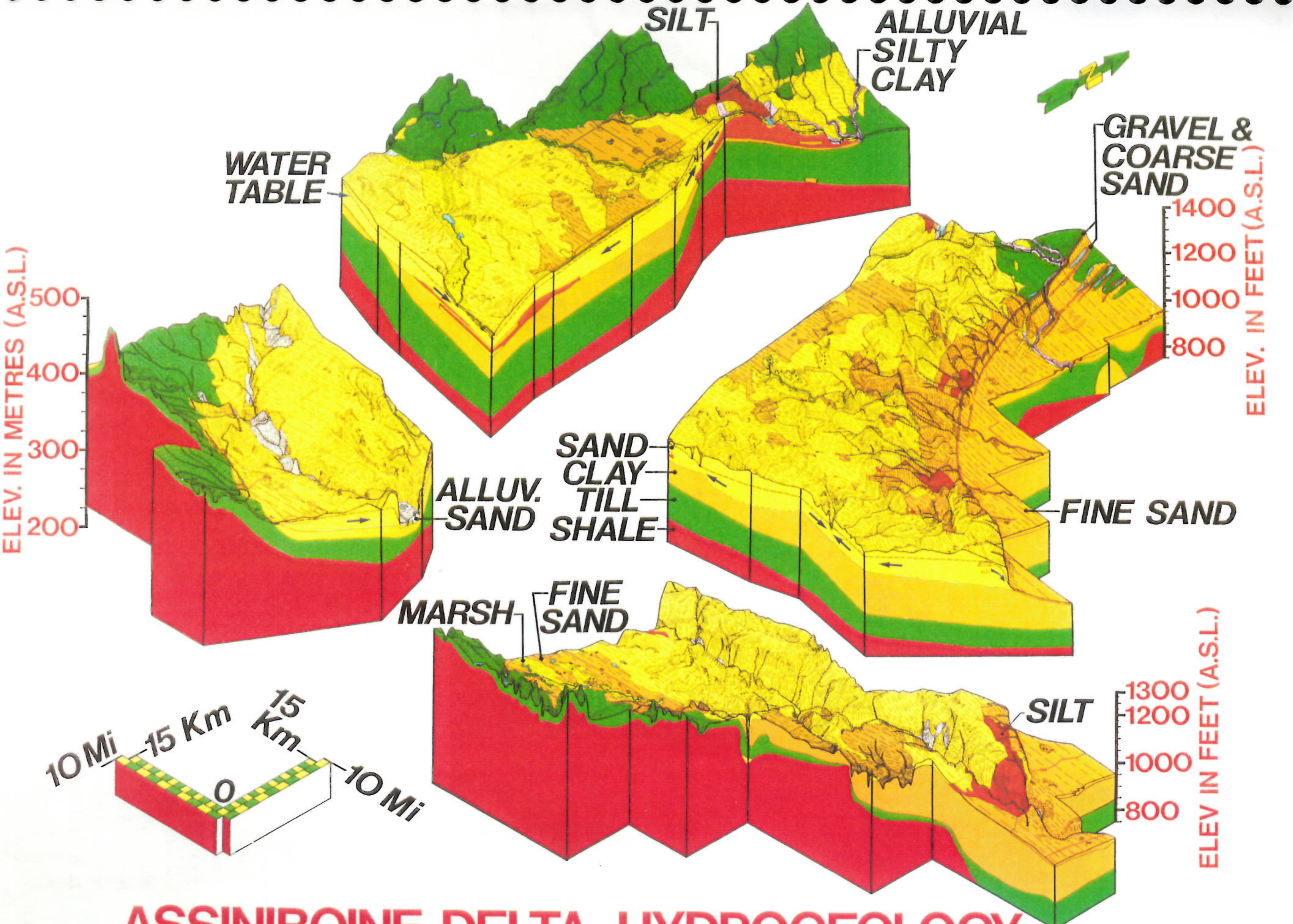
1.4 Hydrogeology

The Assiniboine Delta aquifer consists of the saturated portion of the sand, occasionally gravel on the west side, top set beds of the former delta. A major feature of the aquifer is that it is almost totally unconfined. The aquifer thickness ranges from a few feet along the extremities of the delta to 200 feet in the northeastern part of the system. The groundwater appears to flow from the stream basin boundaries towards the flow channels. The density of groundwater monitoring stations is not sufficient to clearly define the groundwater divide for each basin. Thus the generalized potentiometric map shown in the section on results does not define the basin groundwater divides. The groundwater levels vary from the ground surface in areas adjacent to streams to over seventy feet below ground level under some of the larger sand dunes and hills between deep erosion scars. The transmissivity of the aquifer ranges from over 500,000 U.S.gals/day/ft. in the southwestern segment to under 5000 U.S. gals/day/ft. along the eastern edge. The storage coefficient values vary from 0.0007 to 0.01. The specific yield is from 0.1 to 0.25. The details of the aquifer are presented later under the discussion of the study results.

The preliminary estimation of the long term annual rate at which water is available from the aquifer is 74,449 acre feet (Fig. 6) (Render 1984).

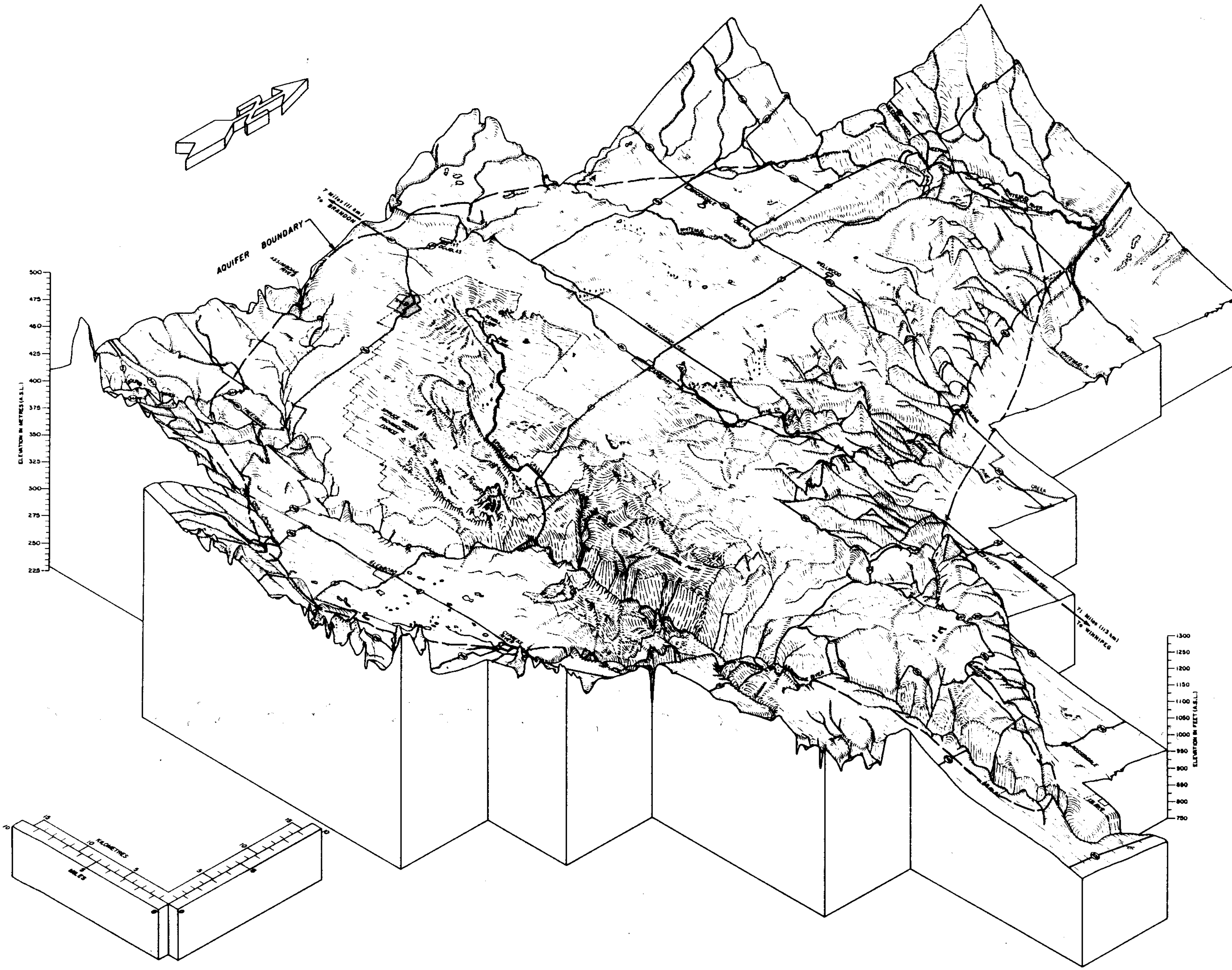
1.5 Development History

Prior to the 1960's the main groundwater development in the ADA was for the Canadian Forces Base at Shilo. The other usage was for domestic supply and farming, particularly stockwatering. In the early 1970's two sites were developed for potato irrigation north of Carberry. From 1976 until 1986 there was a continued increase in the number of irrigation pivots. The first unit was installed in 1977 in section 3, township 10, range 17, wpm. This unit belonged to Shilo Farms. It is capable of irrigating one section without corner coverage. Subsequent to the success of this unit, Shilo Farms installed another 30 units to the south and west of the first unit (Fig. 7). The economic recession of 1982 slowed the development of irrigation. However in 1985 five pivots were installed. In 1986 it is anticipated that 16 additional units will be established.

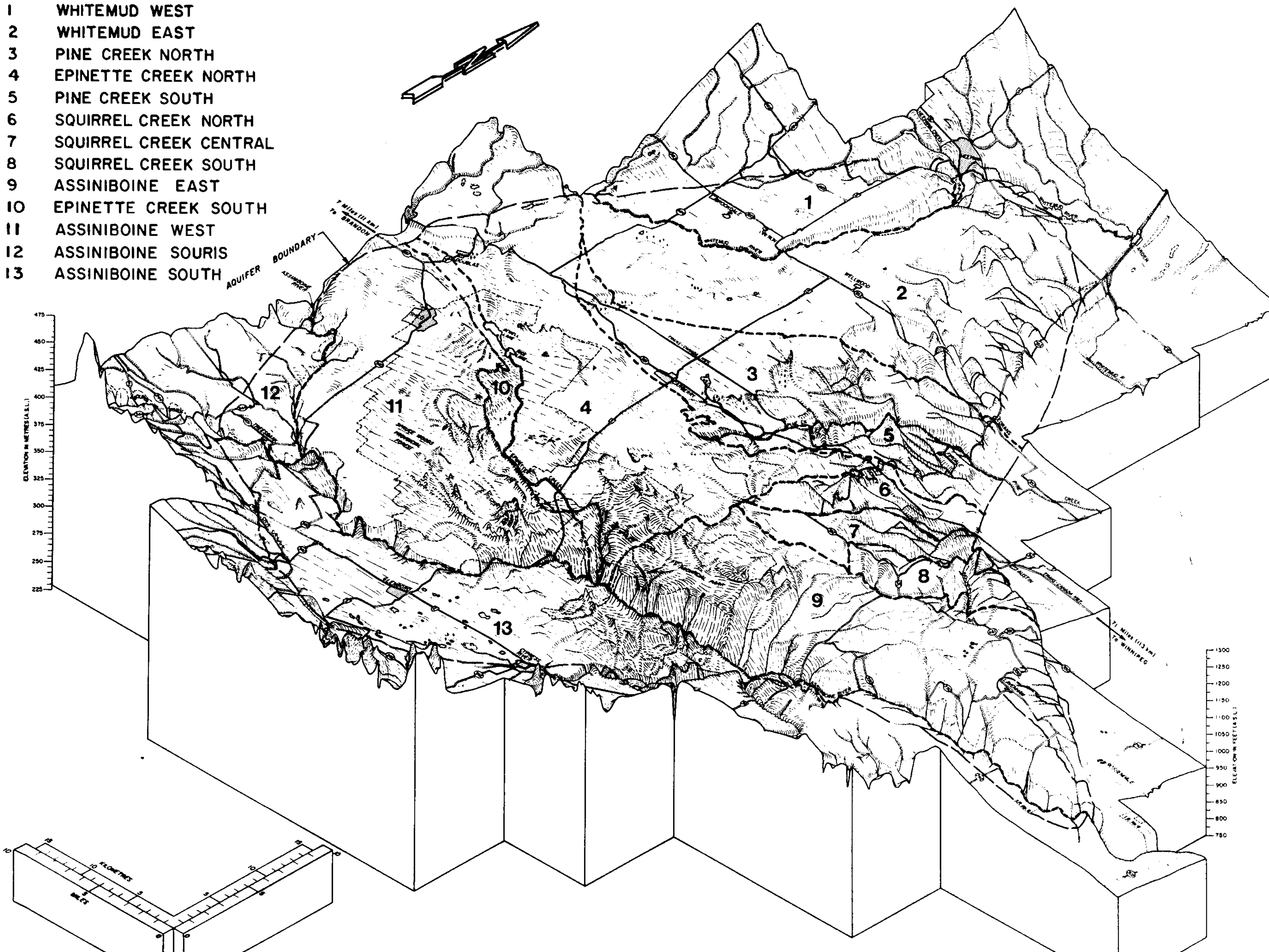


ASSINIBOINE DELTA HYDROGEOLOGY

PLATE 2



ASSINIBOINE DELTA AQUIFER TOPOGRAPHY



ASSINIBOINE DELTA AQUIFER SUB-BASINS

FIGURE 26 OF 88
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Chapter 2

OAK LAKE AQUIFER

2.1 Previous Investigation

The Oak Lake basin, adjacent to the Assiniboine River valley, was known since early recorded times. The associated sand and gravel units forming the Oak Lake Aquifer (OLA) cover an area of some 800 square miles lying within the quadrangle formed by Hartney, Melita, Virden and Griswold (Fig. 1).

During 1964 the Water Resources Branch under the direction of Mr. L. Gray undertook a test drilling program in the southwestern segment of the aquifer (Gilliland and Rutulis, 1968). Other test drilling was done in this aquifer during the 1960's as a part of Town water supply investigations such as the Hartney (Gray, 1963) and Souris (Rutulis, 1969) studies. A considerable amount of drilling was undertaken in the south-central part of the aquifer as a result of groundwater interaction with the construction of the Maple Lakes Drain in 1968. In 1977 further test drilling was done during a regional groundwater study of the Virden area (Betcher 1983).

During the activities in the 1960's a number of groundwater monitoring stations were installed. Most of these stations were of the two inch diameter variety. However a seven inch diameter monitoring station capable of being equipped with a automatic recorder was established in the vicinity of the village of Broomhill. Similar monitoring stations were established as a part of other local investigations at Hartney, Grande-Clairiere, Bernice and south east of Griswold. These monitoring stations have been observed continuously since the early 1960's. The construction of the Maple Lakes Drain and associated groundwater problems resulted in additional test drilling and groundwater monitoring in the south central portion of the aquifer during 1968. In the latter case the monitoring stations were all two inches in diameter and have not been included in the regional groundwater monitoring network. These wells are, of course, providing valuable data with respect to model calibration particularly with regard to surface water groundwater interaction.

As a part of the studies done in the mid 1960's, aquifer parameter pumping tests were undertaken to evaluate the groundwater system for local water supplies at sites to the northwest of Hartney, (Gray, 1961, Personal Communication) and south-east of Griswold (Rutulis, 1969). During 1965 the Water Resources Branch performed a pumping test in Section 12, Township 5, Range 27 wpm, to evaluate a narrow but relatively thick section of the aquifer south-east of Broomhill as a source of irrigation water (Rutulis, 1966). During 1970 the University of Manitoba did some fifty auger test holes to further define portions of the aquifer northeast of Broomhill (Bakhtiari 1971). In December 1971 the University of Manitoba Department of Agricultural Engineering undertook a pumping test in this area on a well capable of supplying water to a quarter section irrigation pivot. This work was undertaken in the southwestern part of the OLA in a zone of gravel generally referred to as the Broomhill aquifer.

The information from these activities has been amalgamated with the data obtained from the project studies and is provided on the drawings presented under the sections on Project 2.1 Investigations and Results.

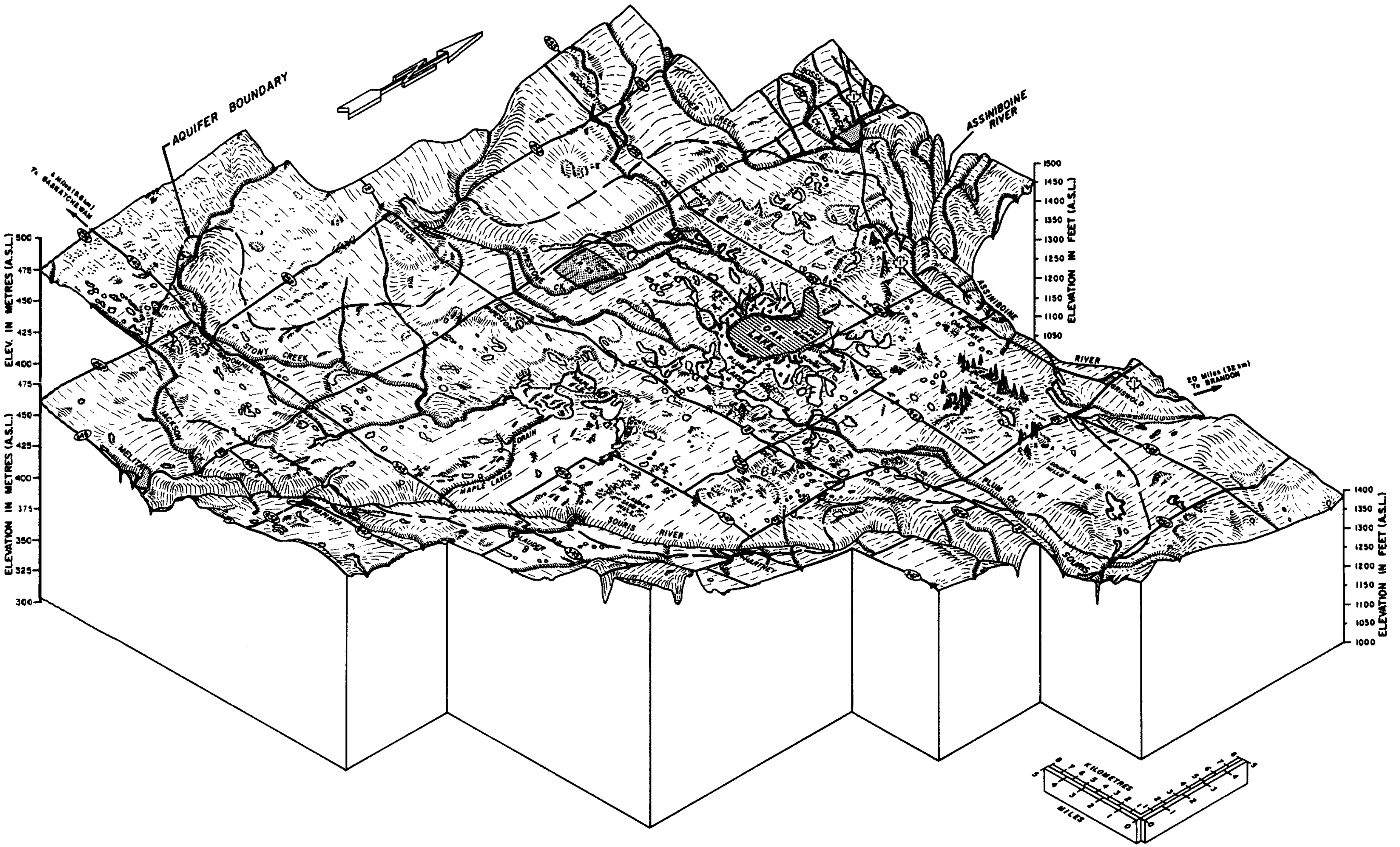
2.2 Topography

The Oak Lake Aquifer area is generally flat (Plate 3 and Fig. 8). However similar to the ADA within a few miles of the main drain, the Souris River, substantial sand duning has taken place. Sand duning has also occurred at various places on the Oak Lake plain.

2.3 Geology

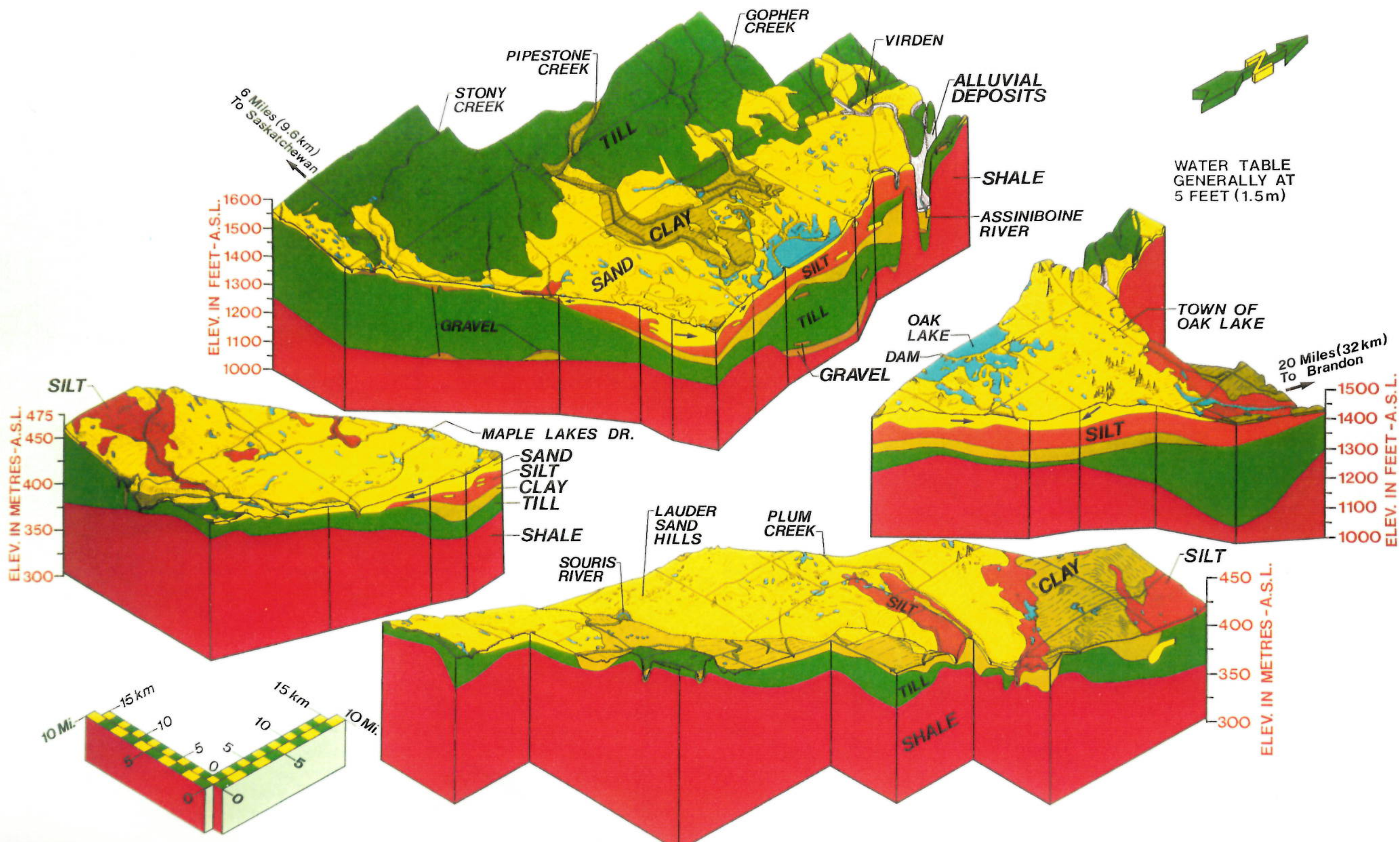
The surficial geology of the Oak Lake basin as depicted on (Plate 4) consists basically of medium to fine sand. On the western extremity, particularly in the south-west coarse sand and gravel form the surface. A fairly extensive zone of clay underlies the west and east central segments of the basin. This clay deposit appears to be related to the Pipestone and Plum Creek channels. The aquifer is bounded on the west and south by glacial till plains. On the north side thin sand plains extend to the deeply incised valley of the Assiniboine River. The eastern side of the aquifer generally blends into an area of silt and clay.

The vertical geology of the aquifer consists of a layer of tan to light grey gravel or silica sand ranging up to 90 feet in thickness resting on sandy silt. The thickness of the sand unit is quite variable over short distances. In one case the aquifer changes from zero thickness, with the silt outcropping, to fifty feet thick over the interval of one mile. The silt in turn rests on dark grey lacustrine clay. As can be seen on the diagram the clays were laid down on glacial till. The till was deposited on the Cretaceous shale bedrock that underlies the whole area. A major feature of the bedrock surface is the



OAK LAKE AQUIFER TOPOGRAPHY

PLATE 3



OAK LAKE HYDROGEOLOGY

WATER RESOURCES BRANCH R.R.P./86

PLATE 4

buried valley that passes through the central part (Fig. 9) of the aquifer area. This feature at a number of places contains gravel zones thirty feet thick along its base.

2.4 Hydrogeology

One of the main features of the Oak Lake aquifer is the presence of a large body of open water in direct connection with the aquifer water table. Oak Lake, the lesser Plum Lakes, Plum Creek, the Maple Lakes Drain and the Souris River act as a drain from the aquifer during most portions of the year. In contrast during the spring meltwater interval substantial amounts of water are injected into the aquifer as a part of bank storage phenomena associated with the creeks that cross the aquifer from the west. These phenomena relate directly to the aquifers' water budget.

The Oak Lake aquifer consists of the saturated segment of the upper sand beds (Plate 4). The saturated thickness varies from near zero to 84 feet.

The water table in general slopes towards the Lakes, Plum Creek, the Maple Lakes Drain or toward the Souris River valley. Thus groundwater flow is towards the same bodies of water. During dry intervals it is quite possible that there is groundwater flow towards the western creek channels.

The Transmissivity of the aquifer is quite variable over short distances. This is due to the gradual decrease in grain size from west to east and northerly from the Souris River and to the fact the aquifer changes thickness, often quite rapidly.

Based on the general similarity between the structure of this aquifer and the Assiniboine Delta Aquifer, making the gross assumption that the surface inflow from the western streams is balanced by the discharge from the Maple Lakes Drain and Plum Creek and evaporation from the Oak Lake, and considering the variation in precipitation between the two aquifer areas it is estimated that the water available from the Oak Lake Aquifer is in the order of 15,000 acre feet per year.

2.5 Development History

Except for the Hartney water supply which was established during 1964 the aquifer until 1978 was developed solely for domestic water supply and stockwatering purposes. During 1979 a corporation named Evergreen Farms developed a quarter section pivot three miles east of Pipestone. Then in 1980 a Mr. Usinear established three quarter section pivots in the southern portions of the aquifer near the Village of Bernice. In 1981 Evergreen Farms added two more units on the original section. The last development was the placing of a quarter section unit in the south east quarter of section 3, township 7, range 24, wpm by a Mr.W.Ransom of Boissevain during 1983.

Chapter 3

GLENORA AQUIFER

3.1 Previous Investigation

The Glenora aquifer was first test drilled during 1973 as a part of the Brandon map sheet study. The sand and gravel nature of the soil that overlies the aquifer allows very fast vertical drainage and thus poor soil moisture conditions in most years. Subsequent to the Water Resources Branch activities test drilling was done by several farmers to identify well capacity prospects. During 1975 one farmer established a pivot system. Also the Water Resources Branch made a surficial inspection of the aquifer and evaluated spring discharge from it along the north shore of Rock Lake. In July 1976 two bench mark monitoring stations were established in the aquifer. As a part of developing irrigation water supplies, three irrigators performed pumping tests on the aquifer. One of these was supervised by a Water Resources Branch engineer.

3.2 Topography

The Glenora aquifer underlies some 25 square miles on the north side of Rock Lake (Fig. 10). The aquifer on the northern side abuts against hummocked till morraine. In contrast to the surrounding area the land surface above the aquifer is very flat.

3.3 Geology

The Glenora aquifer consists of beds of coarse sand to medium gravel that are generally in the order of 30 feet thick. The gravel unit appears to have been deposited into a small glacial lake basin by a vigorous meltwater stream. In many places the gravel contains large amounts of clay. The deposit rests on lacustrine clay beds which in turn are set on glacial till. The till in turn rests on Cretaceous shale. The upper portions of the clay unit where exposed next to a highway cut along Rock Lake in the south east portion of the aquifer consists of layers of clay intercalated with beds of sand or gravel some few inches to one foot thick. The clay beds become progressively thicker and purer with depth.

3.4 Hydrogeology

The Glenora aquifer is unconfined. The aquifer water levels are generally 10 feet below ground level. The saturated thickness is therefore in the order of 20 feet. Replenishment appears to be by direct infiltration over the aquifer surface. The recharge rate was initially estimated at 1500 acre feet per annum. The Transmissivity of the aquifer is quite high being measured at between 50,000 and 75,000 U.S. gals/day/ft.

The recharge rate for this aquifer has been estimated at 1360 acre feet per year (Render, 1983).

3.5 Development History

The first irrigation development in the aquifer occurred during the autumn of 1975. This was followed by two more units during the summer of 1976. Three more units were installed in 1984. Only two of these units had been brought into operation by the autumn of 1985. The current rate of development is approaching the estimated capability of the aquifer. However as the actual pumpage is not being monitored the total usage is not available. This is certainly one aquifer where exact monitoring of the discharge rates is critical to management decisions.

Chapter 4

WINKLER AQUIFER

The Winkler aquifer was first investigated in 1960 as a source of water for the Town. Previously water had been obtained from it for private water supplies within the Town. However due to the nature of the well construction the water was usually brackish or saline. During the early 1960's the Water Resources Branch carried out substantial drilling and sites for initial fresh water wells were sited to the north of the Town (Fig. 11). Also in 1962 the Geological Survey of Canada carried out test drilling over the northern segment of the aquifer and performed a pumping test in the south east corner of section 36, township 3, range 5, wpm. (Charron 1964). The Geological Survey also did further test drilling in 1966 and 1967. The Manitoba Water Resources Branch has done test drilling at various times over the past two decades to locate water supply wells.

4.1 Topography

The area in which the Winkler aquifer is situated being along the forefront of the Pembina Escarpment has a steep slope that rises twenty feet to the mile towards the west (Fig. 12). Of course the land slope rises rather dramatically six miles west of the aquifer where the Pembina Escarpment occurs. There is a slight rise towards the north. However in general terms the land over the aquifer is devoid of topographic variations being a uniform lake bottom plain. The only significant variations are those formed by the creek channels.

4.2 Geology

The Winkler Aquifer system consists of a major upper sand and gravel unit paired with a lesser lower unit that lies some two miles to the east of the former (Figs. 13, 14 and 15). There is some possibility that the two units may be weakly interconnected east of the northern part of the upper deposit. The aquifer boundary shown on the maps encompasses the identified parts of the system.

The aquifer units rest predominantly on Mesozoic shales of the Melita and Swan River Formations (Figs. 13 and 14). The shale units contain minor sandstone and carbonate rock beds. However in the area of the upper unit the Swan River Formation contains a relatively thick fine grained sandstone. This unit is correlated with similar sandstone beds that outcrop near Swan River, Manitoba and with the Dakota Sandstone to the South. Thus the sandstone beds in the vicinity of the Winkler Aquifer are probably part of an extensive system (Rutulis 1984).

Towards the west of the aquifer the bedrock surface (Fig. 16) rises steeply to the upland plain between the Pembina Escarpment and the Pembina River valley. Along the escarpment and in the upland area many exposures of shale bedrock occur. Directly under the upper aquifer the bedrock surface forms a shelf several miles in extent. Some two miles east there is a gouge in the bedrock surface some 200 feet deep. Klassen et al, 1970b postulate this bedrock surface low is part of a buried valley system that extends northerly and south easterly.

The information on the lower sand and gravel unit indicates it is situated against the western outside wall of the postulated buried valley. The deposit rests on shale or glacial till. The bottom of the unit is some 200 feet lower than the base of the upper member (Fig. 13). Though coarse sand and gravel have been intercepted most logs suggest that the unit is composed of fine sand. At some places the total thickness of the deposit is in the order of 200 feet. Due to the fact that there have been very few test holes into the buried valley deposits, evaluation of the northern and southern extensions is not possible. The feature is overlain by glacial till and a one hundred foot thick layer of lacustrine clay.

The upper unit is sitting on glacial till, shale or sandstone. Due to the coarse nature of the deposit it has often been difficult to drill to the base of the thicker parts. However as depicted on the profile, Figure 15, glacial till has been detected under the gravel at some places. At other positions the sand and gravel are almost certainly in contact with shale or sandstone (Fig. 14). Charron, 1962, reports drilling into 45 feet of sandstone under glacial till in the north east corner of LSD 14, Section 5, Township 3, Range 4, wpm. The relationship of the sand and gravel to the Swan River Sandstone is crucial to the interpretation of the aquifer hydraulics. While the situation is obscure, the occurrence of saline water in the lower parts of the upper unit strongly suggest that the aquifer is in direct contact with the sandstone. The upper deposit has an average configuration of one mile wide, 100 feet thick, by 17 miles long. The hydrogeologic profile illustrates the north south structure of the aquifer. The sand and gravel are generally overlain by substantial thicknesses of clay, silt and till. The thickness of the clay layers over the aquifer is shown on Figure 17. The aquifer material appears to have been deposited within a deep tunnel or crevice within the ice thus accounting for its steep side slope configuration.

Surficial silt and sand units adjacent to and up the topographic slope west of where the aquifer is exposed are a significant part of the geologic setting (Fig. 18). Their thickness, in what is here in called the aquifer lateral recharge area, is represented on Figure 19. The vertical relationship to the sand and gravel materials is depicted on the hydrogeologic cross-section Figure 13.

4.3 Hydrogeology

The lower aquifer unit consists of the saturated sand and gravel in the bedrock valley. The material appears to be generally fine so that in most cases the hydraulic conductivity will be low. There is no aquifer test data for this unit however the large thicknesses could result in substantial transmissivity values. Test wells constructed in the western side of the deposit in 1967 indicate the potentiometric surface was in the order of 865 feet asl. Unless this aquifer segment is completely hydraulically separated from the upper unit the potentiometric surface has probably declined significantly. The recharge paths for this aquifer appear to be downward through the overlying clay and till. Thus recharge would be restricted. A water sample taken in the western side of the aquifer in 1967 indicated total dissolved solids of 786 mg/l and chloride ion concentration of 72 mg/l. However the water quality conditions in the lower aquifer are obscure.

The upper aquifer consists of the saturated elongated deposit of sand and gravel illustrated on Figures 13 and 15. Except for a small area of some two square miles, over to its north end the aquifer is confined by the overlying clay deposits. Thus the aquifer has a very small recharge area in the classic sense. The surficial sand and silt beds are in contact with the exposed section of the aquifer thus allowing some lateral water flows to enter the aquifer, from the west, in the surface sand zone. Also in the exposed segment of the aquifer the Shannon and to a lesser extent the Deadhorse Creek channels intercept the aquifer.

Currently the depth to water in wells within the deposit is generally fifteen feet from ground surface. The water levels have generally been declining since 1971 (Fig. 20). The potentiometric surface slopes from the north towards the south. Pumping tests have generally only been done on single wells. However the Geological Survey of Canada performed a multi well test in LSD 2, Section 36, Township 3, Range 5W near the northern thickest portion of the aquifer (Charron 1962). The geology of the site, test hole 8F, Charron 1962, strongly suggest that the aquifer at the site was unconfined. Based on this premise interpretation of the data suggests that the transmissivity at the site was in the order of 380,000 gals/day/ft. Considering that the area affected by the test probably has an average saturated thickness of 200 feet the apparent hydraulic conductivity is 1900 gallons per square foot per day. The specific yield is in the order of 0.20. Depending on the nature of the material and its thickness at a particular location the aquifer transmissivities could vary from 1000 to 380,000 gals/day/ft. The transmissivity in the north central thick section of the aquifer varies between 100,000 and 380,000 gal/day/ft. In the central segment of the aquifer near Winkler the transmissivity appears to be in the order of 100,000 gals/day/ft. The storage coefficient values realistically should range from 0.0001 to 0.01. The specific yield could range up to 0.25. This is because while most of the aquifer is confined below the glacial till and clay the extreme northern portion is unconfined. The single well transmissivity values calculated by the specific capacity method have not produced satisfactory values therefore no evaluation has been attempted for transmissivity in the southern portions of the aquifer. However as the aquifer is thinning in that direction there is no doubt that the values would be declining.

The potentiometric surface slopes southerly along the axis of the aquifer. Considering the high transmissivities the indications are that substantial amounts of water are moving to the central part of the aquifer where most of the wells are situated. Further south the gradient flattens and the transmissivity is less and the lateral flow is reduced.

The lower section of the deposit where it rests on the Mesozoic bedrock of the Swan River formation is generally brackish to saline in water quality. The occurrence of sandstone which is known to contain saline water under the aquifer provides a source for the brackish water in the lower parts of the aquifer.

4.4 Recharge Relationships the Upper Winkler Aquifer Unit

Due to the critical nature of the Winkler Aquifer to the area water supply and the fact the water levels are declining a special section on recharge has been prepared for this aquifer. This analysis was conducted in late 1986.

The most obvious source of fresh water replenishment for the aquifer is the open gravel quarry at the north end. This quarry which covers some 30 acres is estimated to contribute 19 acre feet per year as the net value between precipitation and evaporation.

The next most direct route for replenishment to the aquifer is the zone of thin overburden that covers the northern end of the aquifer. This is deemed to consist of two zones. One is an area of 1.1 square miles of silt and fine sand that directly overlies the aquifer. If the recharge rate of the Pine Creek Basin, with similar soil and hydraulic conditions, of 0.109 feet per annum can be assumed for the area of direct infiltration then 77 acre feet would accrue to the aquifer on a long term annual basis.

The second zone has a silty-clay, clay cover that ranges up to 10 feet in thickness. Under even small gradients the infiltration rate for this zone would be close to that for the silt and fine sand area. Therefore the recharge rate of 0.109 feet was also used for this area of one square mile. Under this assumption the portion of recharge from the

0 to 10 foot clay zone would be 70 acre feet.

Another source of potential recharge is water flowing down slope through the unconfined thin silt and sand aquifers that lie west of the northern portion of the aquifer. While a substantial area of some 30 square miles of unconfined silt and sand aquifer lie west of the Winkler aquifer much of the estimated 2100 acre feet of recharged water that infiltrates yearly discharges relatively quickly in the spring and early summer into Deadhorse and Shannon Creeks or is transpired through the summer. Unfortunately the flow area hydraulic conductivity and gradients towards the aquifer prime intake zone are sufficient to move only a small portion of this water into the Winkler aquifer.

It is considered reasonable that water would flow from the surficial deposits toward the aquifer through the silt, sand and thin clay zone overlying the aquifer. The mechanics of the surficial flow towards the upper unit of the Winkler aquifer are depicted on Figure 13.

The average gradient in the surficial deposits is 50 feet to 2.75 miles, or 0.00344. The average sand-silt thickness along the flow front just west of the Winkler Aquifer is 10 feet (Fig. 19). The water table is generally in the order of five feet below ground level. Thus the saturated thickness can be considered to be in the order of five feet. As shown on Figure 20 the boundary flow lines towards the prime infiltration areas for the aquifer are some 2.6 miles apart. A reasonable estimation of the hydraulic conductivity value for the sediments in the surficial aquifers is 100 gallons per square foot per day.

Thus applying Darcy's Law the lateral flow towards the top of the Winkler Aquifer:

$$Q = \frac{100 \times 2.6 \times 5280 \times 5}{6.229 \times 43560} \tag{4.1}$$

$$= 25 \text{ acre-ft} \tag{4.2}$$

The above described recharge systems could be considered to have the potential to function naturally. The estimated total recharge from these sources is 191 acre feet per year. It is interesting to observe on Figure 20 that until the estimated yearly withdrawal rate exceeded some 200 acre feet per year the aquifer water levels fluctuated about a median level of 273.2 metres. As the withdrawal rates exceeded 200 acre feet per year the aquifer commenced to decline steadily. This phenomena continued despite the fact that the declining water level caused downward hydraulic gradients through the aquifer roof that were steadily increasing. Until 1985 the only significant interruption of the water level decline occurred during intervals of above average precipitation. The cessation of water level decline and slight recovery during 1985 appears to be due to a reduction in irrigation water withdrawal combined (Fig. 20) with and probably resulting from, above mean rainfall. The steep recovery in early 1986 coincides with above mean precipitation during the spring and early summer.

4.5 Induced Recharge

Once the water levels in the aquifer started receding below the water table at some 273 m a.s.l. downward infiltration through the clay zones commenced. The leakage through the clay would directly increase as the water levels declined. Currently on an average basis the potentiometric surface averages 10 feet below the water table (the water table being assumed at 5 feet below ground level). The upper aquifer unit clay cover thickness and the approximate outline of the aquifer sand body are shown on Figure 17. The vertical hydraulic conductivity of the clay based on it being one tenth the mean horizontal clay hydraulic conductivities provided by Day 1977 is 7×10^{-10} ft/sec. This value is probably optomistic for the lower section of the thicker clay units. Using this hydraulic conductivity the estimated downward leakage for each clay thickness range over the upper aquifer unit is 124 acre feet per year.

4.6 Stream Induced Recharge

Over the years since 1971 as the groundwater levels declined the hydraulic head in Shannon and Deadhorse Creeks, particularly at times of significant flow, rose above the potentiometric surface in the aquifer. Currently during the spring floods and following periods of heavy rain the water levels in the streams are above the elevations of the potentiometric surface. The discharge data for Shannon Creek indicates that water would be available in the channel some 100 days per year. The stream bed materials are estimated to have a vertical hydraulic conductivity in the order of 7×10^{-7} ft/sec. A reasonable estimate of the vertical hydraulic gradient would be 1. It is estimated that the length of the flow channel over the exposed section of the aquifer would be 1.6 miles. The average water surface width is about 20 feet. Based on these gross assumptions the current yearly average recharge through the bottom of the stream channels is 23 acre feet.

The accumulated current recharge estimate from all sources is: 338 acre feet per year.

4.7 Development History

The development of the aquifer commenced in 1963 when two wells were developed to the north of the Town by the Manitoba Water Supply Board (Fig. 11). The wells are pumped at low rates of 50 gallons per minute in order to control the drawdown and consequently the tendency for the saline water in the lower section of the aquifer to rise towards the well intakes. During 1967 one additional Town well was installed.

Three wells were placed in 1968. These were followed by two more in 1981. By 1986 the Manitoba Water Services Board had eight wells operating for the Town and three community wells for the surrounding municipalities. The water usage by the Town is shown on Figure 20.

The Town wells pump 500 acre feet per annum. The current estimated rate for the community wells is 58 acre feet. Kroeker farms reported an average rate of 119.54 acre feet per year for irrigation for the first five years of the 1980's. This system has been in operation since 1971 when it was originally licensed for 80 acre feet (Figure 20). The irrigation system naturally uses more water on hot dry summers. This accounts for the peak water usage from the aquifer during 1983. It is estimated that several livestock farms in the area withdraw another 40 acre feet. Thus the current total withdrawal estimate on an annual basis is 697 acre feet. The southern end of the aquifer potentiometric surface shows a small gradient to the south. Due to the fact that the data for the aquifer in this area is not sufficient to quantify the flow the amount of discharge to the south has not been determined. However rudimentary calculations indicate that very little water is flowing out of the aquifer to the south. The comparison of these discharge estimations with the postulated rate yearly recharge rate of 338 acre feet indicates that the aquifer fresh water is presently being mined at a rate of 359 acre feet per year. The rate of water withdrawal shown on Figure 20 indicates that with the continued growth in the area this mining rate will likely increase.

Over the past fifteen years since the major water level decline commenced (Fig. 20) it is estimated 6750 acre feet have been withdrawn from the upper unit of the aquifer. Of this amount it is estimated that 2865 acre feet was recharged through the thin overburden area of 2.03 square miles inside the 10 foot clay thickness contour (Fig. 17). The declining water levels induced a gradual increase in leakage through the overlying beds which accumulated to in the order of 930 acre feet over the fifteen years. Assuming that the unconfined area of the aquifer north of Deadhorse Creek has an effective specific yield of 0.20 the 10.5 foot water level decline would withdraw 2728 acre feet from storage. The confined 45 square miles of the aquifer contributed 30 acre feet because of the declining water levels. The total amount of water contributed by recharge and mining was estimated at 6554 acre feet. While the above values are estimates they do coincide reasonably. The surplus would presumably have been made up by saline water seepage from the underlying Swan River sandstone aquifer. Most of the saline water seepage would have occurred during the early 1980's as the water level decline approached a current maximum. During 1985 and 1986 as a result of above average precipitation reducing water demand and increasing the recharge rate in the unconfined area the water level decline stopped and some recovery occurred (Fig. 20). However with the apparent potential for increased usage there is little doubt that the water level decline will commence again once the precipitation events return to normal or less. Thus the water levels should again decline at a rate of 0.7 feet per annum or more. Based on the above hydraulic evaluation it is anticipated that of the current amount of fresh water mining fifty five percent or 197 acre feet will be withdrawn from storage and the remaining water will presumably be made up by the influx of saline water from the Swan River Formation. It is anticipated that for a time as the drawdown increases a larger portion of the residual will be replaced by saline water in the lower sections of the aquifer. However viewing Figure 15 it can be seen that once another ten feet of drawdown occurs the unconfined area of the deposit will increase considerably and the weight in providing the residual will probably return to removing water from storage. In any event whether the water level decline is reduced by the influx of saline water or not the effect is that 359 acre feet of fresh water is removed from the aquifer each year.

Despite these considerations there is little likelihood that the water system is in immediate jeopardy. Indications are that there are 230 thousand acre feet of potable water above the 250 mg/l isochlor in the central one mile wide, eight mile long northern portion of the aquifer.

4.8 Groundwater Chemistry

The water quality in the upper unit of the Winkler Aquifer varies both with depth in the aquifer (Fig. 15) and from north to south. The Swan River Sandstone unit is reported to have water containing 34,000 mg/l total dissolved solids. The Roland Community well located in the north end of the aquifer adjacent to the recharge area had a total dissolved solids value of 441 mg/l when it was installed in October 1977. The Rhineland Community well located towards the southern end of the aquifer at a similar depth had a total dissolved solids content of 1006 mg/l when it was installed in October 1975. The quality of the water is invariably better adjacent to the top of the aquifer.

In general the water quality is deteriorating within the aquifer. Even at the north end of the aquifer the quality in the Roland Community well had increased to 807 mg/l total dissolved solids by June 1983. Because this well is in a thick highly permeable portion of the aquifer adjacent to the recharge area the change in quality is particularly ominous. Through the central sections of the aquifer the water quality varies with the rate of pumping, the proximity of the observation well to a pumping well and the depth of the well intake within the aquifer. However in the case of the well shown on Figure 20 the location is at some 300 feet from the pumping well. Therefore there is some indication that the salinity is moving gradually upwards due to the general decline in the potentiometric surface. In the southern part of the aquifer a observation well adjacent to a community well with its intake at the 150 foot level has shown a chloride ion increase from 460 mg/l in January 1983 to 960 mg/l in October, 1986. During the same interval the community well with its intake between 85 and 100 feet below ground level showed a chloride increase from 185 to 270 mg/l. While the chemical data are related to pumping well situations that tend to destabilize the fresh water/salt water relationships the data suggest the fresh water quality in the aquifer is deteriorating. The water quality in the lower unit of the Winkler Aquifer is generally unknown.

Chapter 5

ELIE AQUIFER

The Elie aquifer was first described by Charron (1964a) in his report on the Fannystelle area. The area was test drilled for the Manitoba Water Supply Board by Mr. M. Rutulis of the Manitoba Water Resources Branch in 1968. Prior to that time the Municipality had established a water loading station using an open water pond that had been developed during quarrying operations as its source of supply. The Elie Aquifer is small in size. However due to the fact that the surface water available for development is difficult and expensive to treat and that the extensive bedrock aquifer that underlies the area contains saline water it is a very important water source.

5.1 Topography

The aquifer exposure is surrounded by the extremely flat Glacial Lake Agassiz clay plain. The gravel, sand and silt deposit that forms the aquifer rises some ten feet above the surrounding plain over an area of approximately one eighth of a square mile (Fig. 21).

5.2 Geology

The geology of the Elie aquifer consists of a dome of silt, sand and gravel, approximately one quarter square mile in area on its base, that is overlain except for its top most portions by glacial lake clay and underlain, at every site drilled so far, by dense carbonate rich glacial till. The structure of the sand and gravel material suggests that it is a kame that formed during the recession of the last glaciation. The unit was then partially eroded by water action in Lake Agassiz and finally mostly covered by clay.The deposit probably originally had maximum thicknesses in the order of 60 feet. However quarrying operations have reduced the thickness of most of the deposit to the order of 40 feet. The glacial till rests on carbonate bedrock of the Silurian Interlake Group.

5.3 Hydrogeology

The lower twenty to thirty feet of the sand and gravel are saturated with fresh water. The system is recharged through the small exposure area. Approximations of the recharge process (Render 1981) suggest that the small exposure of sand and gravel allows 36.34 acre feet of recharge per year. The water originally seeped downward into the bedrock. However as a result of pumping the fresh and saline water heads are close to equilibrium. Prior to development a substantial fresh water zone had developed to the west of the recharge area in the bedrock aquifer. The bedrock aquifer is saline in all directions from the Elie aquifer site.

5.4 Development History

Following the initial gravel quarrying a Municipal pumping station was established in the south-east corner of the deposit during 1941. By the early 1980's the withdrawal from the pumping station was in the order of 22 acre feet per annum. In 1965 a water supply well for the village was established in the south-west part of the fresh water zone (Fig. 21). This well withdrew 24.32 acre feet per year from the aquifer. The result of the two pumping systems was that there was an overdraft on the aquifer. The saline water in the bedrock aquifer encroached into the fresh water zone and the water quality in the village well deteriorated. Consequently the Municipality was asked to reduce the amount of water withdrawn from the loading station. Also in 1985 the village water supply well was moved into the sand and gravel deposit proper.

Chapter 6

MIAMI AQUIFER

6.1 Topography

The aquifer underlies a eastward sloping land surface at the foot of the Pembina escarpment. From the western edge of the aquifer on the west side of the Village the land rises steeply to the west up the face of the escarpment some 600 feet. Even across the known aquifer which extends some two miles east of the village the land drops another twenty five feet. The land surface then extends eastward across the relatively flat glacial lake plain.

6.2 Geology

The Miami aquifer has been drilled through in only a few sites adjacent to the village (Rutulis, 1968). This work indicates that the aquifer consists of up to seventy feet of sand and gravel resting on a thin layer of glacial till that is underlain by Cretaceous shale (Fig. 22). The deposit appears to be elongated in the south south easterly and north north westerly directions from the village. The aquifer is overlain by five or more feet of silty glacial lake clay except where the Tobacco Creek Channel has incised the clay cover to near the top of the aquifer. The deposit is situated at the foot of the Pembina Escarpment and appears to be in contact with the sand and gravel of a overlying glacial lake beach that occurs along the toe of the escarpment.

6.3 Hydrogeology

The aquifer is a confined unit that appears to have maximum thickness of 75 feet. The aquifer is confined above by silty glacial lake clay and is underlain by dense shale

(Fig. 22). The water levels vary from ground level to some five feet below ground surface. Two aquifer tests have been carried out on the aquifer one by the Water Resources Branch for the Village well and the second by Miami Feeders for the feedlot well water supply. These tests indicate aquifer Transmissivity between 30,000 and 50,000 U.S. gals/day/ft. (Petsnik, 1979, 1978 respectively). The recharge rate of the aquifer is not known. However the fact that a spring located in the Number 23 Highway drain some one half mile to the east of the village is still discharging suggests that the pumpage has not reached the replenishment rate. Water levels in this aquifer have generally been rising over the eight years of observation.

6.4 Development History

The aquifer was test drilled and developed as a water supply for the Village of Miami by the Water Resources Branch for the Manitoba Water Supply Board during the spring of 1968. The Village utilizes some 15 acre feet per year. The only other development in the aquifer occurred during 1978 when Miami Feeders developed two wells for the purpose of stock watering. One of these wells supplied water to the feedlot until 1983 when the operation terminated.

Chapter 7

PROJECT 2.1 INVESTIGATIONS

The investigations commenced in the summer of 1980. The first task was the establishing of the aquifer systems that would be investigated (Fig. 1). The aquifers chosen were selected on the basis of their importance to the rural development and on the apparent magnitude of their capacity.

The program was divided into three phases including 1) establishing aquifer dimensions and aquifer monitoring network 2) establishing aquifer hydraulic characteristics and 3) aquifer capability analysis. These program elements are shown in Figures 23, 24 and 25.

7.1 Phase I

Phase I consisted of reviewing the previous information for the aquifers and evaluating the additional data needed to make comprehensive aquifer management determinations. The work done for the Assiniboine Delta Aquifer is representative of the program for the other aquifers studied. In view of the fact that this aquifer covers the largest area and has the greatest capacity for future development, it received the majority of the investigative activity. The approach used was to divide the aquifer into sub basin units (Fig. 26). Then within the sub-basin existing groundwater monitoring stations such as MH-6 (Fig. 27) were identified. Next a network of groundwater monitoring stations was selected based on the Theisen Polygon procedure (Fig. 28). The approach was to have a monitoring station for every thirty-six square miles of aquifer surface area. In general this was achieved. The Oak Lake aquifer was divided in a similar way (Fig. 29). The smaller aquifers were instrumented by placing monitoring stations in areas that had not already been instrumented. Because of the small size of these aquifers the Theisen Polygon approach was not warranted as the density of monitoring station to provide a pattern would have been excessive.

Once the monitoring station networks had been approved and supplies obtained, the first field activity of constructing monitoring stations commenced in the Oak Lake Aquifer in September 1980. The work schedule is outlined on the bar graph (Fig. 30). With a couple of months break during the winter this program was completed for all aquifers in November 1981. The work involved drilling a total of 201 test holes, collecting and analysing some 4000 soil samples, constructing 97 monitoring stations equipped with automatic recording instruments, and performing 50 single well pumping tests. At some of the monitoring station sites the typical deep well screened near the bottom of the aquifer was combined with a shallow well with the screen just below the water table. These installations were established to confirm the vertical directions of water movement in the aquifers. Also they allow the assessment of the effects of evapotranspiration on the upper and lower portions of the aquifers. The design of a typical observation well is shown on (Fig. 31). The design of the wells combined with the excellent groundwater quality encountered suggests that these wells should easily last the fifty year designed life. In order to minimize the amount of monitoring work required, the new automatic water level recorders were equipped with clocks that allowed three months of unattended observations. Towards the end of the agreement some of the sites located in difficult terrain were equipped with recorders that can operate unattended for seven months. A listing of the test holes and wells drilled is provided in Table I. The distribution of test holes over the two aquifers is shown on Figures 32 and 33. The logs for the test holes and the construction of the wells have been published in Manitoba Water Well Driller's Reports for the years 1980 to 1985 inclusive.

The data obtained from these activities were analysed over the winter of 1981/82. Major parameter improvements were the development of preliminary Transmissivity, Aquifer Thickness and Potentiometric Maps. A presentation of the results and the proposed continuation of the program was made during February 1982 to the first annual meeting of the International Association of Hydrogeologists in Winnipeg.

AUTOMATIC PUMPING TEST

PLATE 5

Chapter 8

PROJECT 2.1 INVESTIGATIONS PHASE II

The second phase of the work consisted primarily of pumping tests. The first activity involved the installation of one or preferably two observation wells adjacent to irrigation pumping wells (Plate 5). The reason that two observation wells were installed was that, that approach allowed the use of the distance drawdown form of analysis. The irrigation farmers cooperated with this program. The PFRA drills installed twenty-three observation wells at fifteen sites during April and May 1982 (Fig. 34). Due to the fact that most of the irrigators do not have meters on their systems it was necessary to install meters on the pivots in all but three cases. During the autumn of 1983 and the summer of 1985 three more irrigation well pumping test sites were developed in the ADA and three in the Oak Lake Aquifer (Fig. 35). Two installations were established in the Glenora aquifer in the summer of 1984. The tests operated essentially automatically. That is when the operator ran the pivot the water was mostly removed from the drawdown cone area and the water level instruments compiled the drawdown and recovery data. They have therefore been referred to as *Automatic Pumping Tests*. In order to accomplish suitable observation frequency, recorders that have to be attended to once a week had to be utilized. However the records that had been obtained have provided a very large increase in the hydraulic data for the aquifer. The data for all these tests is on file with the Water Resources Branch. Selected water level drawdown and recovery records and log/log plots from these tests are provided in Appendix A, Book IV . One other incidental facet of this work was that considerable data was obtained on the actual operation of the irrigation pivots. All this information will be very useful in constructing and calibrating aquifer models.

Following the construction of the irrigation well pumping test sites, formal contracts were developed for the construction and performance of standard unconfined aquifer pumping tests. The layout of two typical tests are shown on Figures 36 and 37. The design of a typical pumping well is shown on Figure 38. These contracts were awarded to private drilling contractors. The wells required for the tests were constructed during the summer. The procedure was to carry out three tests each autumn after the growing season had ended and the recovery from transpiration effects had essentially ceased within the aquifers. Three tests were done in the ADA in 1983. During 1984 one test was done in the ADA and two tests were undertaken in the OLA (Figs. 34 and 35). For 1985 one test was carried out in each of the ADA, OLA, and Glenora aquifers. Appendix A provides the layout, pumping well design, water level drawdown and recovery records, log/log time drawdown plots,and log/log distance drawdown plots for these tests. Table II provides a listing of the contractors and costs of this work.

In order to analyse the data obtained from these tests a standard procedure was required both in constructing the test installations and in analysing the information obtained. As is well known Walton (1979) the analysis of even the highest quality of pumping test data for unconfined aquifers is fraught with difficulty. The following approach was used in analysing the tests undertaken during the project. The spacing of the observation wells was designed to eliminate the effects of the partial penetration of the pumping wells. Also observation wells were screened near the bottom of the aquifer so that the hydraulic flow lines passing through them would be essentially horizontal. The amount of drawdown in nearly all cases was a small percentage of the total thickness of the aquifer so that the reduction of the saturated thickness and thereby the transmissivity was minimal during the test. The Walton (1970) procedure was used to evaluate distance drawdown plots for transmissivity (Fig. 39). The distance drawdown analysis because it reflects the effects the pumping had on a considerable segment of the aquifer provides a more concrete determination of the transmissivity than the point determination from time drawdown analysis. In some cases the distance drawdown graphs for times near the end of the test also provided good specific yield analyses. Once the transmissivity was determined then the value was used in conjunction with the log/log time drawdown plots for the observation wells (Fig. 40) to determine the storage coefficient and the specific yield utilizing the Prickett (1965) method. The values determined are presented on Figures 34 and 35. Hydraulic conductivities were determined by the standard procedure of dividing the transmissivity by the aquifer saturated thickness.

In addition to the major tasks described, other activities related to the hydraulics of the aquifer were undertaken. These were increased snow survey stations, (Figs. 41 and 42) a local resident operated rain gauge network in the ADA and OLA (Figs. 43 and 44), a rain gauge system underneath the pivot at selected irrigation sites, soil moisture sampling in the upper one foot of the soil zone (Fig. 45), and attempts to monitor groundwater discharge to streams. In the latter case one cut-throat flume was established adjacent to the Assiniboine River south-west of Shilo and meter and gauge board observations were taken along the Assiniboine River and Pine Creek. Also water level recording stations operated by Canada Water Resources Branch were used to evaluate groundwater discharge rates. In particular the Station for the Upper Pine Creek was used as a bench mark. These parts of the work were undertaken from 1982 to March 1986. A special survey network was developed based on snow water sampling in wooded areas (Fig. 46). This approach was taken in an effort to obtain *snow trap* type observations.

In order to evaluate the groundwater flow through typical sections of the ADA and OLA and consequently to assess the distribution of hydraulic conductivity a line of piezometers were constructed in each aquifer (Figs. 27, 47 and 48). To the extent possible these lines were constructed along groundwater flow lines developed from the potentiometric maps for these aquifers. This activity was undertaken during the spring of 1984 in the OLA and during the autumn of 1984 in the ADA. At some of the sites previous well installations were combined with the new wells to form the profile.

During the drilling of the initial set of monitoring wells it became evident that in both the ADA and the OLA the vagaries of the aquifer structure and thickness were such that large portions of the aquifers were not definable in detail. To alleviate this situation the PFRA sampling drills worked in the aquifers several times during 1983 through 1985. During this work a total of seventy-one test holes were drilled. The footage drilled and samples collected were included with the similar work in Phase I. A part of this work was the locating and sampling of pilot holes for the formal pumping test pump wells. This data was very significant in developing the geologic structure of the aquifers and in defining the hydraulic conductivity.

During the summer of 1983 as a part of a Federal/Provincial evaluation of the use of remote sensing in various scientific activities, the Aquifer Capacity study included an evaluation of ground cover determination from ERTS data (L. Horn and F. Render 1984). The study required ground truthing for calibration purposes. This was accomplished over the ADA in a period of three days. The results, based on the determination of the area covered by various crops were good.

Several sites for monitoring spring groundwater discharge were proposed during the various phases of the study. The installation of one cut throat flume was undertaken along the north bank of the Assiniboine River to the south west of Shilo. The site chosen is directly south of some of the Shilo area irrigation pivots.

The costs of the project for each fiscal year are shown on Table III. The total cost excluding salaries and PFRA drill costs was 662,000 dollars.

Chapter 9

PROJECT 2.1 INVESTIGATIONS PHASE III

The Phase III activities to March 31, 1986 were largely devoted to data evaluation. The results of these activities are presented in the section on results. In the case of the ADA, the data was essentially ready for incorporation into the computer model. Significant work remained to be done on the OLA, Glenora Aquifer and Winkler Aquifer to provide the basic input parameters for aquifer digital computer modelling. In these aquifers it is estimated fifty percent of the evaluation remains to be accomplished. In addition to data evaluation the digital computer groundwater model utilized by the United States Geological Survey was brought into the VAX system. As of March 31, 1986 it was in place at Manitoba Water Resources.

Note: Review of Winkler Aquifer completed in December 1986.

Chapter 10

RESULTS

The investigations determined several basic parameters that are inherent in the evaluation of aquifer capability. These factors are depth to water, potentiometric surface definition, water level fluctuations, saturated thickness, hydraulic conductivity, transmissivity, precipitation and groundwater discharge. The improvement in the basic data files were mainly for the Assiniboine Delta and Oak Lake aquifers. However substantial additional hydraulic information was obtained for the Glenora aquifer. In regard to the Winkler and Miami aquifers mainly geologic structure information were obtained. In both these cases observation wells were constructed *Table I.* The main activity in the Elie aquifer area was stratigraphic test drilling and soil sampling to try and concretely define the aquifer structure (Figs. 21 and 49).

10.1 Groundwater Monitoring Networks

On the long term aquifer management perspective, the major contribution of the Canada-Manitoba Aquifer Capacity agreement was the establishment of comprehensive groundwater monitoring systems in all the aquifers except Miami. In the latter case the aquifer definition drilling was not completed prior to the end of the agreement so that completion of the groundwater monitoring network was not possible.

The major groundwater monitoring networks for the ADA and OLA are shown on (Figs. 27 and 50). The ADA system was augmented by 60 automated wells and the OLA by 30 automated wells. The groundwater monitoring networks for the Glenora and Winkler Aquifers are shown on Figures 10 and 51. Prior to the system being augmented there were several monitoring stations in each system. Some of these were for special purposes such as monitoring the effects of the Maple Lakes Drain on the Oak Lake Aquifer or determining water level and quality changes near pumping wells in the Winkler Aquifer. A number of the monitoring stations installed under the agreement were for pumping test purposes and were to be dismantled once the data compilation had been completed. Selected hydrographs for various sections of the aquifers are presented on Figs. 52 to 60. The charts show the effects of snow melt water and heavy precipitation events. The curves also record the dry conditions for the early part of the 1980's and the recovery of the water levels following the relatively high precipitation events of 1984, 85 and 86. Groundwater level hydrographs for the monitoring stations established during the project and for selected pre-project stations are provided in Appendix B.

The water level monitoring system also allows for the determination of the depth to water. This factor is important in calculating saturated thickness and in estimating pumping hydraulic head. Depth to water maps were developed for the ADA and OLA (Figs. 61 and 62). The depths to water were not contoured because topographic variations, particularly in sand dune areas, cause erratic changes in the depth to water. An interesting situation is the increase in the depth to water from 20 feet to 72 feet as the edge of the upland plain is approached south-east of Wellwood (Plate 1 and Fig. 3).

Another aspect of the groundwater monitoring system was the ability to observe daily evapotranspiration. The charts showed daily drawdown and recovery curves particularly in treed areas. The daily fluctuations are open to analysis. The values obtained indicate the amounts of water that were returned to the atmosphere. The values are conservative. This was because the observation wells were usually established on higher ground. There were often numerous swamp or depressed areas that would transpire much more intensely particularly in the Spruce Woods Forest Reserve. When the estimates of transpiration were combined with the evaluation for the forested portion of the aquifer provided by the ERTS study, an evaluation of the water loss from the treed areas was possible. Unfortunately this approach was not feasible for the grassland and agricultural areas. The reason for this was that the crop roots in most cases did not intercept the water table so that the observation well water levels were not affected on a daily basis.

The major capability of a comprehensive groundwater monitoring network is the ability to determine on a scheduled basis the net change in groundwater storage within the aquifer system. This is a integral part of the aquifer water budget. It is also a strong indicator of the trend of aquifer storage in regard to water development and natural discharge. The ADA lost some 2 billions gallons of water over the interval 1981 to 82, (Fig. 63). However during the interval 1981 to 1985 the storage substantially recovered so that the loss was only 0.5 billion gallons (Fig. 64). These are examples of how the groundwater monitoring stations can be used in conjunction with other related parameters to manage the aquifer on the appropriate time frame.

10.2 Potentiometric Maps

The data for the groundwater monitoring stations was used to develop potentiometric maps of the aquifers (Figs. 65 and 68). With the automatic continuous system the water table can be developed over the aquifer at any particular time or season of the year. When related to the elevations of the bottom of the aquifer this map allows an interpretation of the overall saturated thickness of the aquifer. An important use of the potentiometric map is the development of flow nets. The combination of the Potentiometric and the Transmissivity maps allow the evaluation of the groundwater discharge from the aquifer. Also under steady state conditions that generally occur in both the large unconfined aquifers the contour spacing of the potentiometric map allow the interpretation of relative values of Transmissivity. That is in the areas where the groundwater flow is relatively constant and the contours are widely spaced the Transmissivity values will be relatively high whereas they will be relatively low in areas with narrow spacing. With regard to the development of accurate groundwater management models the definition of the potentiometric surface and its fluctuations are essential to proper calibration.

10.2.1 Potentiometric Map For the ADA

The potentiometric map for the ADA (Fig. 65), reflects the high flat elevation area in the north west where a high permeability zone exists. In general, groundwater flows to the east and south from the elevated area. Of course it must be recognized that whenever there is sufficient water to recharge the aquifer it infiltrates to the water table over the whole aquifer and contributes to the flow moving from the areas of higher elevation. Basically the contours indicate what is already physically and intuitively known. That is that the majority of the flow is towards the Assiniboine River. In the field this phenomena is evidenced by numerous springs and seeps along the banks of the River between the Shilo and Holland areas. Similarly there are significant discharges to the Whitemud River and Pine and Squirrel Creeks. However in these latter cases the density of the monitoring stations system and the deflection of the potentiometric surface near these streams is not sufficient to dramatically define the flows. In the field the discharge indicated for the eastern side of the aquifer by the potentiometric map is very evident in the numerous small streams that flow across the Campbell Strandline of former Lake Agassiz.

The slope of the water table under the south-west segment of the aquifer indicates that water may underflow Epinette Creek. This is important from the viewpoint of the amount of water that can be pumped to the south of Epinette Creek without degrading the aquifer capacity. While the situation is subtle and could be redefined by intense irrigation pumping to the south it appears from the surface evidence at this time that the creek is in fact a boundary to flow from the north and south.

10.2.2 Potentiometric Map Of The Oak Lake Aquifer

The potentiometric map for the Oak Lake Aquifer (Fig. 66), shows that the water flows towards Oak Lake on the west and north side of the system. In the east the flow is generally away from the lake and towards Plum Creek. On the south side of the aquifer as would be expected the flow is towards the Souris River. On the west side of the aquifer several small streams and drains bring water from the till upland towards Oak Lake. During the spring melt and the occasional interval of heavy rain these streams recharge the system. At other times the channels drain water from the aquifer into the lake. The Maple Lakes Drain is a special case in this case groundwater is generally draining into the drain. The situation is reversed during the spring when water from Stony Creek flows into the Maple Lakes Basin and thence out through the Maple Lakes Drain. During these times the upper reaches of the drain function under bank storage conditions and water flows into the aquifer. Of course once the run off interval is over the groundwater seeps back into the drain along its entire length.

10.2.3 Potentiometric Surface Of The Winkler Aquifer

The potentiometric surface for the Winkler aquifer slopes southerly from the recharge area in the north-west corner of the aquifer (Fig. 67). The indications from the potentiometric surface map is that the recharge area for this aquifer is relatively limited. Also the water level elevations combined with the transmissivity estimations suggest that there is a very little flow of water southerly out of the aquifer. The potentiometric relationship in the lower Winkler Aquifer unit have not been monitored and are therefore unknown.

10.2.4 Potentiometric Surface Glenora Aquifer

The potentiometric surface of the Glenora Aquifer (Fig. 68) generally slopes from the north-west portion of the aquifer southerly to the Rock Lake basin or on the east towards the small stream that drains that portion of the aquifer into the Pembina River.

10.3 Sand Thickness

10.3.1 Assiniboine Delta Aquifer

The sand and gravel units that form the basis for the Assiniboine Delta aquifer are generally thinner along the western edge where they are coarser. Through the north central and north east the sand beds are generally thicker (Fig. 69).

10.3.2 Oak Lake Aquifer

The sand and gravel units that form the Oak Lake aquifer are much thinner than those in the Assiniboine Delta area. The thickness also varies rapidly from place to place (Fig. 70). However basically the beds tend to be thicker in the central and southern portions of the aquifer.

10.3.3 Glenora Aquifer

The Glenora aquifer over its some 25 square miles is composed of coarse sand to fine gravel. The beds are generally 30 feet thick (Fig. 71).

10.3.4 Winkler Aquifer

The sand and gravel beds that constitute this aquifer extend in a northerly direction from some seven miles south of the Town of Winkler to approximately ten miles north (Fig. 72). The deposits are 200 feet or more thick at some places in the north central section of the aquifer. The deposit is complex in structure as illustrated on Figures 13 and 15. The grain size varies from silt size to gravel. Large segments of the lower portions of the aquifer consist of gravel. However the deposit has very steep edge slopes and *pinches* out rapidly on its north east and west sides. The sand and gravel portion gradually declines in thickness and width to the south. While the extremities of the base of the deposit are up to three miles across at some places the main body of the deposit is narrow being in the order of one mile in width.

10.3.5 Elie Aquifer

The structure of the sand and gravel units that form this aquifer, despite its small size are quite complex. The features are depicted on Figure 49.

10.3.6 Miami Aquifer

The features of this aquifer have not been defined. However where it was fully penetrated by drilling in its central sections it is composed of sand beds in the order of 75 feet thick. Electromagnetic investigations (Betcher 1982) indicate the aquifer may underlie some nine square miles along the fore- front of the Pembina Escarpment.

10.4 Saturated Thickness

Saturated thickness maps have been prepared for the ADA, OLA, Winkler and Glenora Aquifers.

10.4.1 Assiniboine Delta Aquifer

Analogous to the sand thickness the ADA saturated thickness tends to be thinner on the west and thickest through the central and north-east areas (Fig. 73). The observation network is not dense enough to determine the variations of aquifer thickness under the various large dune areas. However it is anticipated that there would tend to be some rise in the water table under the large dunes and therefore some increase in the saturated thickness.

10.4.2 Oak Lake Aquifer

Similar to the ADA, the OLA saturated thickness follows the trends of the sand thickness (Fig. 74).

10.4.3 Winkler Aquifer

The Winkler Aquifer being mostly a confined aquifer has a saturated thickness that is basically synonymous with the sand thickness (Fig. 72). The exception is at the northern end where the aquifer is unconfined. In that area the saturated thickness is ten to fifteen feet less than the sand and gravel thickness.

10.4.4 Glenora Aquifer

The Glenora Aquifer is thickest towards the western extremity (Fig. 75). The saturated thickness over the eastern half of the aquifer is barely sufficient for normal irrigation well development.

10.5 Hyraulic Conductivity

Sufficient data was available to construct hydraulic conductivity maps of the Assiniboine Delta and Oak Lake aquifer areas. Even in the case of these aquifers data from a number of sources including formal project pumping tests, farm irrigation well pumping tests performed by the Water Resources Branch, well driller pumping tests, production well specific capacity data and grain size information were employed to develop the maps. The above sources have been listed in order of quality. Therefore in utilizing the maps the nature of the control should be considered.

10.5.1 Hydraulic Conductivity of the Assiniboine Delta

The hydraulic conductivity of the Assiniboine Delta Aquifer was mapped to a degree suitable for aquifer modelling (Fig. 76). Due to the nature of the deltaic deposit that constitutes the Assiniboine Delta Aquifer coarse material was laid down basically where the ancestral river entered Lake Agassiz at the head of the large bay that terminated near Brandon. The material became progressively finer from west to east as the delta extended out into Lake Agassiz. Consequently the hydraulic conductivity values are highest near the apex of the delta and decline towards the east. The values range from the 5000 to 3000 USgal/ft^2/day in the Shilo area to less than 100 USgal/ft^2/day along the eastern fringes of the aquifer. The contortions of the 1000 USgal/ft^2/day contour line illustrate the complex nature of the grain size variations and there by the intricate history of the deposition of the aquifer skeleton.

The definition of the hydraulic conductivity over large portions of the aquifer was possible because of the detailed soil sampling that had been done during the test drilling. Soil analysis data from pumping test sites were correlated with hydraulic conductivity determined from the tests (Fig. 77). The formula determined was then used with soil analysis data from test hole sites, where no pumping tests had been done, to estimate the hydraulic conductivity.

10.5.2 Hydraulic Conductivity of the Oak Lake Aquifer

A hydraulic conductivity map (Fig. 78) for the Oak Lake Aquifer was developed in a similar fashion to that for the Assiniboine Delta Aquifer. As the geologic setting of the two aquifers is similar and as the Assiniboine Delta Aquifer grain size formula gave reasonable results it was decided to use it to estimate hydraulic conductivity from test hole soil sample mechanical analyses for the Oak Lake Basin. The hydraulic conductivity mapping in the extreme south-west corner of the aquifer near Broomhill was largely extracted from Bakhtiari (1971).

The structural development of the Oak Lake Aquifer seems to have been by the coalescing of several small deltaic deposits along the western side of the lake basin. The deposits in the central and eastern parts of the basin appear to be deltaic forset beds that have been modified,at least in part, by wave action. The result is that there is a general decrease in grain size from west to east and south to north. The hydraulic conductivity values are in the 1000 to 2000 USgal/ft^2/day range in the south and west and grade to less than 100 USgal/ft^2/day in the central,north and east parts of the aquifer. The low values in the center of the aquifer appear to be related to fine grained sedimentation in the deeper parts of the Glacial Lake Souris Basin. Along the north side of the Souris River in the south central sections of the aquifer the hydraulic conductivity attains its highest values with one test site having a value of 5500 USgal/ft^2/day. However even in these areas there are occurrences of clay extending up through the aquifer to ground surface. These features occur locally in relatively thick sand and gravel zones giving the impression that they may be monadnocks of a finer grained lake bed sequence that predated the emplacement of the coarser material.

10.6 Transmissivity

10.6.1 Transmissivity of the Assiniboine Delta Aquifer

A transmissivity map suitable as an initial basis for aquifer modelling was developed for the Assiniboine Delta Aquifer (Fig. 79). The transmissivity similar to the hydraulic conductivity decreases from west to east. Despite the fact that transmissivity is also a direct function of the saturated thickness the hydraulic conductivity values appear to predominate in this aquifer. The result is that the trends on both maps are very similar.

The predominant feature of the transmissivity map is the crescent shaped zone of high transmissivity, defined by the 60,000 USgal/ft/day contour line, that extends from the Wellwood area in the north-east around to where Epinette Creek crosses PTH No. 5 in the south central part of the aquifer. Both the north-east and south-east limbs of the zone appear to be related former channels of the glacial Assiniboine River. There is a similar trend where the present Assiniboine River cuts through the western segments of the aquifer. The Epinette Creek channel which is certainly a former river channel seems to be associated with a zone of low transmissivity along its central segment. The transmissivity values range from 200,000 to 60,000 USgal/ft/day in the high transmissivity zone to less than 5,000 gal/ft/day along the eastern edge of the aquifer. While there is a predominant trend of declining transmissivity from west to east there are zones of low transmissivity within the central portions of the aquifer. These are usually associated with considerable thinning of the aquifer sands and saturated thickness. These anomalies indicate it is prudent to test drill before any serious development decisions are made.

Basically once the transmissivity value is below 5000 USgal/ft/day the prospects for developing a quarter section irrigation water supply is remote. Therefore it would appear that the eastern 25 percent of the aquifer is not suitable for groundwater irrigation development using standard groundwater well procedures.

10.6.2 Transmissivity of the Oak Lake Aquifer

As a basis for modelling the Oak Lake Aquifer a transmissivity map has been developed (Fig. 80). For any particular site the transmissivity has either been taken from some type of pumping test or has been estimated by multiplying the hydraulic conductivity map value by the saturated thickness.

Due to the erratic nature of the Oak Lake Aquifer saturated thickness (Fig. 74) the transmissivity map must be used with caution. An example is the change over an interval of 2 miles from a transmissivity of 200 000 USgal/ft/day to zero at the site some 8 miles north of Napinka. A similar situation has been intercepted off the south-west corner of Oak Lake.

The highest transmissivity values occur to the west of the Maple Lakes Drain half way between the Maple Lakes Basin and the Souris River channel. In this area the transmissivities range from 220 000 to 50 000 USgal/ft/day The indications are that this zone extends under most of the area influenced by the Maple Lakes Drain. This has been a factor in the impact that the drain has had on the water table in the surrounding area. As can be seen on the map the southern high transmissivity zone extends north-easterly to a point north of Hartney.In this area relatively thick and coarse saturated deposits result in high transmissivity values. Even with low hydraulic conductivity values transmissivities capable of transmitting irrigation system water supplies to wells can occur where the saturated thickness is substantial. Despite these considerations fifty percent of the aquifer area has transmissivities below 5000 USgal/ft/day (Fig. 80) so that the development of irrigation well water supplies for quarter section pivots is not practical. Even in areas with good transmissivity values the erratic nature of the aquifer thickness and hydraulic conductivity make it mandatory to carry out test drilling prior to any major development scheme.

10.6.3 Transmissivity of the Glenora Aquifer

Similar to the ADA and OLA systems the Glenora aquifer tends to have higher transmissivity on the western end. However in the case of this small aquifer the grain size variation from one end of the aquifer to the other is not as pronounced as in the larger aquifers. The lower transmissivities on the eastern and north eastern portions are due predominantly to an increase in clay infill in the gravel pores and not necessarily due to smaller grain size in the overall matrix. The Transmissivity towards the eastern end of the aquifer, as determined by the formal pumping test done during the Project, was 76,000 U.S. gals/day/ft. This test work showed that it was possible to improve the permeability near production wells in the north eastern part of the aquifer by jetting development and treatment with sodium acid pyrophosphate.

10.6.4 Transmissivity of the Winkler, Miami, and Elie Aquifers

Transmissivity mapping of the Winkler, Miami, and Elie aquifers was considered. However, in the case of the Winkler Aquifer, there was insufficient data to develop a comprehensive map. The knowledge of the transmissivity of this aquifer was undertaken in late 1986 and has been discussed in Chapter 4. The transmissivity values range from 100,000 to 380,000 U.S. gals/day/ft. in the thick core sections to in the order of 1000 U.S. gals/day/ft. along the periphery. Because of the delicate nature of the saline-fresh water interface further testing in specific areas will be necessary.

The Miami aquifer has not been defined well enough to warrant transmissivity mapping.

The Elie aquifer is quite small. Unless further action is taken with regard to artificial recharge, development of a transmissivity map does not appear to be warranted.

10.7 Storage Coefficient

The only data on the Storage Coefficient of the unconfined Assiniboine Delta and Oak Lake Aquifers was obtained from the formal pumping tests carried out in these aquifers during the Project. The data indicate Storage Coefficient values between 0.0006 and .001 for the ADA and between .0005 and .10 in the OLA (Figs. 34 and 35).

The Storage Coefficient for the Winkler Aquifer varies from in the order of 0.01 along the edge of the unconfined northern segment of the aquifer to 10^{-4} in the thinner confined southern parts of the aquifer.

10.8 Specific Yield

The Specific Yield parameter is essentially equal in importance to those of transmissivity and hydraulic conductivity. Due to the fact that it was possible to preform sixteen irrigation well pumping tests in the ADA area there are a significant number of specific yield determinations (Fig. 34). The specific yield for the ADA ranged between 0.11 and 0.39. The lower values tend to be associated with fine materials and short duration pumping tests. The higher values were determined from long to very long term pumping tests. In some cases irrigation wells were operated as long as ten days with only short interruptions for oil checks. The long term pumping allowed the water that adheres to the sand grains that form the aquifer structure to drain downwards. Thus there was a more complete accounting of the water within the drawdown cone resulting in a higher specific yield determination. The very high specific yield values such as the 0.39 values were determined from long term pumping tests in coarse sand and gravel materials.

There were only three specific yield determinations for the OLA. The values ranged from .1 to .29 (Fig. 35).

The Specific Yield for the Glenora Aquifer pumping test was 0.25.

The Specific Yield for the northern unconfined segment of the Winkler Aquifer is in the order of 0.25.

10.9 Precipitation

Precipitation data for the ADA and OLA were collected during the last three years of the investigation. An example of the snow surveys is shown on (Figs. 2 and 81). The water available was low during the first three years of the project. However during the interval from 1983 to 1986 the snow concentration improved. This effect is also shown on the groundwater level hydrographs. The *wooded area* snow survey conducted during 1985 and 1986 (Fig. 82) generally showed a more uniform distribution of the snow water. This was because the poplar woods act as a more uniform snow catcher. The conclusion is that the latter survey indicates more accurately the amount of snow water lying on the land surface.

The rainfall distribution over the summers of 1983 to 1985, at station ADA-R01, is presented on Figure 83. An example of the areal distribution of the rainfall over the summer of 1983 is shown on Figure 84. As can be seen the rain varied considerably over relatively short distances. This factor caused an attempt to evaluate irrigation water application by the use of rain gauges to fail. This was because the passage of individual storm cells often crossed the off field gauges and not the on field ones. The result in some cases was that there was more rain off the field than under the irrigation system. The years 1981, 1982 and 1984 had relatively low rainfall, whereas 1983 and the interval from mid 1985 through 1986 had above average rain.

The combined rain and snowfall for the year 1983 is shown on Figure 85.

One aspect of the snow water and rainfall observations was that they illustrate as shown by the Figures that the precipitation events vary considerably from one portion of the aquifer to another.

Despite the relatively good precipitation during the latter years of the project, significant increases in groundwater levels did not commence until the spring, 1986 when the melt water was added to the good antecedent (1985) rainfall.

10.10 Soil Moisture

The soil moisture program was relatively restricted. Data was collected at only a few sites in the ADA and OLA.The locations of the scheduled soil moisture sampling networks that were developed in the latter years of the project for the ADA and OLA are shown on Figures 86 and 87. The variation of the soil moisture in the upper one foot of the soil zone, at Station ADA 29, during the interval 1983 to 1986 is illustrated on Figure 88.

10.11 Stream Flow Metering

The stream flow monitoring on the Assiniboine River (Harrison, 1986) indicated that the groundwater discharge from the aquifer between Brandon and Holland was in the order of 100 cfs during the period September 12 to October 14, 1985. Mattick and Wagner (1968) indicate that the groundwater inflow over this reach of the river for the years 1963 to 1967 inclusive varied from 100 cfs in the autumn to as high as 600 cfs in June. Harrison provides flows over this period for the reaches Brandon to Treesbank Ferry, Stockton Ferry, Provincial Trunk Highway Number 5 Bridge, and Provincial Trunk Highway Number 34 Bridge of 8.33, 5.8, 28.67 and 57.8 cfs respectively.

The cut-throat flume on the spring near Shilo (Fig. 27) indicated that the discharge varied from 103 USgpm in July of 1985 to 197 USgpm in September, following the cessation of plant growth and irrigation, to 135 USgpm on March 21, to 197 USgpm in April 1986 following the snow melt.

10.12 Groundwater Chemistry

The main thrust of the investigations was oriented towards providing data for quantitative evaluation of the aquifers. However when conditions allowed samples were taken for water quality. A compendium of the samples acquired mainly in the AD and OL Aquifers is presented on *Table IV*. The locations of the stations sampled are shown on the various groundwater monitoring network maps. The water quality in the ADA is good to excellent for irrigation; electric conductivity ranging between 200 and 700 micro mhos per liter. The water is also potable. The occurrence of nitrate (nitrogen) analytical values in excess of 1 mg/L at some of the irrigation well sites is a cause for concern that some farm chemicals may be entering the aquifer system under the irrigated areas.The water quality in the OLA is generally good for irrigation and potable purposes. However in some areas, *Table IV*, the water exceeds both irrigation and drinking water standards. The unexpected poor quality of the water at the site of the OLA 59 pumping test where the electric conductivity ranged between 1200 and 1360 micro mhos exemplified the situation. It also indicated that caution on water quality is required in establishing an irrigation system in the Oak Lake Aquifer. Water quality in the Glenora Aquifer is good for both irrigation and potable purposes. The dissolved mineral content of the Winkler Aquifer ranged from very good in the recharge area with total dissolved solids less than 500 mg/L to saline in the lower sections of the aquifer with the total dissolved solids exceeding 30,000 mg/L at some places. The Elie Aquifer water quality was similar to the Winkler Aquifer having total dissolved solids under 500 mg/L in the exposed sand and gravel area with total dissolved solids exceeding 10,000 mg/L in the underlying bedrock aquifer. The water quality in the Miami Aquifer was potable with total dissolved solids ranging from 600 to 800 mg/L.

Chapter 11

CONCLUSIONS

Project 2.1, Aquifer Capacity component provided a very large increase in the data base available for the two major aquifers; the Assiniboine Delta and the Oak Lake. Definitive long term regional water level monitoring networks were established in these two aquifers. Substantial increase in data and monitoring capability were also attained in the Glenora, Winkler and Elie aquifers.

The Assiniboine Delta aquifer was the aquifer were most of the work was undertaken. In this case the parameters required for aquifer digital computer modelling were attained to reasonable engineering requirements. Of course over such a large aquifer there are still many areas that have no definition of the hydraulic parameters. Also from the viewpoint of the hydrologic budget the data for evaluating the discharge to streams was not sufficient for definitive analysis. Similarly the data on the changes in the soil moisture content in the unsaturated zone were not addressed during the study. Therefore it was not possible to evaluate this budget parameter.

In the case of the Oak Lake aquifer the data is sufficient for attempts at computer modelling. However due to the vagaries in the aquifer thickness the evaluation of this aquifer will be more difficult. Also the interaction with the surface water system will add considerable difficulty to the calibration process on a long term basis.

The data obtained from these investigations combined with previous data should allow quantitative evaluation of the Glenora and Elie aquifers.

In the case of the Winkler aquifer where saline water underlies the fresh water, the aquifer hydraulics have not been defined. Also the nature of the bedrock contact with the aquifer material has not been determined. This factor is imperative to definitive evaluation of the quantity of water that can be withdrawn without destroying the aquifer water quality. The potential of the eastern lower unit is unknown.

There are several sources of additional information that can be gleaned from the aquifers at relatively little cost. Examples of these are single well pumping tests at untested monitoring stations, testing of irrigation wells constructed in new areas of the aquifers, additional stream flow monitoring and additional test drilling in the Winkler and Miami Aquifers.

Some of the later test drilling, particularly the work done in late 1985 suggested that there may be areas in the ADA underlain by a fine grained lower aquifer. If this unit is fairly extensive, it may provide enough water to increase well capacities to that required for irrigation in some of the less productive parts of the aquifer. Similar conditions are present in some parts of the OLA.

The deep aquifer in the buried channel under the Oak Lake aquifer could provide an additional source of water in the area and may have the potential to store surface run off water during periods of high stream flow.

Discharge to streams and general stream aquifer relationships require better understanding if the Assiniboine, Oak Lake, Glenora and Winkler aquifers are to be competently managed.

The Whitemud River basin in the northern portion of the Assiniboine Delta aquifer is particularly susceptible to stream flow reduction. Should the development of irrigation groundwater supplies starts to approach the annual groundwater discharge rate to the stream.

The quantitative evaluation of the aquifers that are under major development will be considerably restricted, if not impossible, if artificial discharge measurements are not maintained.

If the hydrologic budgets are to be defined, soil moisture measurement facilities will be required in the aquifer systems.

The clay zone in the north central parts of the ADA has considerable impact on the agricultural land use of the area. This is because it provides the basis for highly productive soil. It also is the best area for making maximum use of irrigation water.

Should the water table begin steady recession, reduction of soil moisture leading to vegetation deterioration and soil surface instability could have a bearing on groundwater development.

The aquifer chemistry in all the aquifers with the exception of the lower portions of the Winkler aquifer and station OLA 59 in the Oak Lake aquifer, are good to excellent from the irrigation and potability viewpoints.

The occurrence of relatively high nitrate values in water from some of the Shilo area irrigation wells is cause for concern with regard to farm chemicals entering the aquifer systems under irrigated areas.

The development of the Winkler aquifer should be limited to municipal use until such time as the mechanics of the salt water movement are clearly defined and the hydrologic budget for the aquifer established.

In order to maintain the thrust provided by Project 2.1 the monitoring systems should be operated and maintained. This will enhance the capability to understand whether development or natural phenomena are causing aquifer reactions. The data provided will allow the verification of analytical predictions.

Chapter 12

FURTHER STUDIES

Work should proceed to develop and calibrate digital computer models of the aquifers studied. The models once calibrated should be used to develop management strategies for each aquifer system.

The monitoring systems established during the program should be operated, maintained and revised as required to provide adequate data to manage the aquifer systems.

There is very beneficial work that could be undertaken in several of the aquifers. This work was not accomplished during the Project as it was considered secondary to the major funded tasks which kept the investigative resources available occupied. Such activities as single well pumping tests on monitoring stations, irrigation well pumping tests, in the Assiniboine Delta and Oak Lake Auifers, pumping tests and deep test drilling through the Winkler Aquifer, and test drilling to define the Miami Aquifer are tasks that should be considered.

Efforts should be made to enhance the understanding of surface and groundwater interaction by improved monitoring systems. In particular a continuous metering station on the Assiniboine River at the Provincial Trunk Highway No. 5 bridge would be most beneficial in deciphering the groundwater discharge from the western reaches of the aquifer.

A ground surface to water table soil moisture monitoring program should be instituted in the Assiniboine Delta and Oak Lake Aquifers to assess the yearly contribution of the unsaturated zone to the groundwater budget.

The monitoring of groundwater withdrawals of over 30,000 gallons per day should be mandatory.

Consideration should be given to evaluating the procedures for applying farm chemicals on irrigated land, either by direct application or through the pivot system, so that excess application occurs to the smallest extent possible.

The six aquifers described in this report do not represent all of the significant aquifers in Manitoba. There are several other, generally small, aquifers that are becoming critical to regional water supplies. Also there is the major Carbonate Aquifer that underlies most of south central Manitoba. Consideration should be given to evaluating the capacities of these aquifers.

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GLOSSARY

Anisotropic - Having some physical property that varies with direction. Most aquifers are anisotropic relative to some properties, e.g. hydraulic conductivity.

Aquifer - A geologic unit that is sufficiently permeable to conduct groundwater and to yield economically significant quantities of water to wells and springs.

Aquifer System - A hydraulically interconnected layered rock sequence including both aquifers and aquitards, which forms an identifiable unit between the recharge and discharge areas of a groundwater flow system.

Aquitard - A confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer; a leaky confining bed. It does not readily yield water to wells or springs, but may serve as a storage unit for groundwater.

Confined Aquifer - An aquifer bounded above and below by impermeable beds, or by beds of distinctly lower permeability than that of the aquifer itself; an aquifer containing confined groundwater.

Darcy's Law - Derived formula for the flow of fluids where the unit flux is directly proportional to the product of the hydraulic conductivity and the gradient; based on the assumption that the flow is laminar and that inertia can be neglected.

Discharge Area - An area in which subsurface water, including both groundwater and vadose water, is discharged to the land surface, to bodies of surface water, or to the atmosphere.

Electrical Conductivity - Capability of a unit volume of water containing dissolved inorganic chemical constituents to conduct electric current. Electrical conductivity generally increases linearly with increases in Total Dissolved Solids. The values are expressed as the reciprocal of electric resistance at 25°C, either as micromhos per centimeter or under the SI system, microsiemens.

Equipotential Line Line joining points of equal hydraulic head or potential on a potentiometric map or flow net.

Flow Line - The hydraulic gradient line on a two dimensional flow net. The zone between two flow lines being a *flow tube.*

Flow Net - An imaginary, two dimensional network of equipotential and flow lines that represent the energy distribution and flow within a groundwater system.

Flow System - Cross-sectional flow net of a groundwater system representing the movement of water from the recharge areas to the discharge area. Often referred to as local, intermediate, regional and continental systems.

Glacial Till - Unsorted, unstratified, and generally unconsolidated heterogeneous mixture of clay, silt, sand, gravel and boulders ranging widely in size and shape, deposited directly by or underneath a glacier without subsequent reworking by melt water.

Groundwater Divide - An imaginary plane separating two or more groundwater flow systems across which no water flow occurs.

Groundwater Monitoring Station - Site containing a spring, well or other device permitting scheduled observation of groundwater parameters.

Hydrologic Budget - An accounting of the inflow to, outflow from, and storage within a hydraulic unit such as a drainage basin or aquifer.

Hydraulic Conductivity - The rate of flow of water through a unit cross section under a unit hydraulic gradient, at the prevailing temperature expressed as gallons per square foot per day.

Hydraulic or Hydrogeologic Profile - A two dimensional representation of an aquifer along a groundwater flow line showing the geology and hydraulic potential distribution.

Hydrogeologic Cross-Section - A two dimensional representation perpendicular to the longitudinal axis of an aquifer showing the geologic structure and potential distribution.

Hydrograph - A graph showing stage, flow, velocity or other characteristic of water with respect to time.

Hydrogeology - The science that deals with subsurface waters and with the related geologic aspects of surface waters.

Isotropic - Medium with properties the same in all directions.

Monadnock - An upstanding hill rising conspicuously above a general level, representing an isolated remnant of a previous erosion cycle.

Moisture Content or Soil Moisture - Ratio or percent of total soil volume in the unsaturated zone that is made up of water.

Piezometer - Device for measuring hydraulic head or pressure at a point within a medium. It usually consists of a sealed tube open to the atmosphere at the top and having a short intake length of well screen or porous tube at the bottom.

Porosity - The percentage of the bulk volume of a rock or soil that is occupied by interstices, whether isolated or connected.

Potentiometric Surface - A surface representing the total head of groundwater and defined by the level to which water will rise in wells or piezometers.

Pumping Test - Test to determine aquifer hydraulic parameters where water is pumped from or into an aquifer and the change in groundwater levels is observed at one or more wells.

Recharge Area - That portion of a drainage basin in which water is absorbed; and under which the net saturated flow is away from the water table.

Saturated Thickness - Thickness of the portion of an aquifer in which all the interstices are filled with water under pressure greater than that of the atmosphere.

Specific Capacity - The rate of discharge from a water well per unit of drawdown over a particular interval of pumping.

Specific Storage - The volume of water that a unit volume of aquifer releases from storage under a unit decline in hydraulic head.

Specific Yield - The volume of water that an unconfined aquifer releases from storage per unit surface area of aquifer per unit decline in the water table.

Storage Coefficient - The volume of water released from storage in a vertical column of aquifer over a unit area under the influence of a unit change in hydraulic head.

Thalweg - Line connecting the lowest points along a valley whether under water or not.

Theisen Polygon Method - Monitoring stations are located on a map and connecting lines drawn to adjacent sites. Perpendicular bisectors of the connecting lines are drawn to form polygons. Parameter values or changes are assumed to be uniform over individual polygons.

Total Dissolved Solids - The weight of dissolved inorganic chemical constituents per volume of water. Usually expressed as milligrams per litre.

Transmissivity - The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. Though spoken of as a property of the aquifer, it embodies also the saturated thickness and the properties of the contained liquid. Expressed as gallons per foot per day.

Unconfined Aquifer - An aquifer having a water table as its upper surface.

Unsaturated Zone - Also zone of aeration or vadose zone. Subsurface zone above the water table containing pore water under pressure of less than atmospheric, and contain pore air and gases generally at atmospheric pressure.

Water Table - The surface between the zone of saturation and the zone of aeration; that surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere.

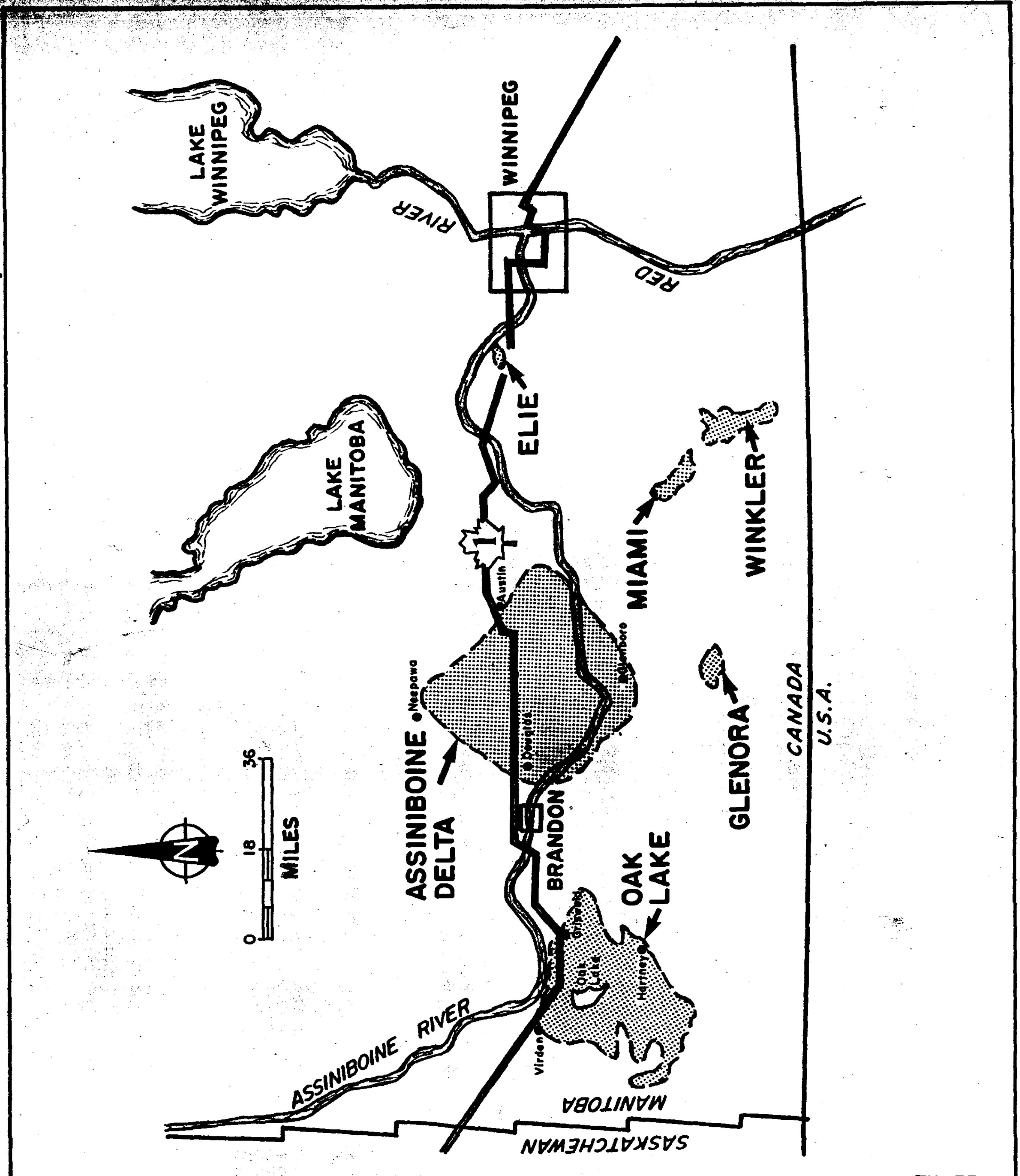


FIGURE 1

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

LOCATION OF PROJECT AQUIFERS

DRAWN: F.B.R.	Manitoba Natural Resources			
CHECKED	Water Resources			
PREPARED: F.W. Render	SUBMITTED	APPROVED		
SCALE: AS SHOWN	DATE: 86 06 27	SHEET: 1 of 88	FILE NO. 90-1-7-1141	

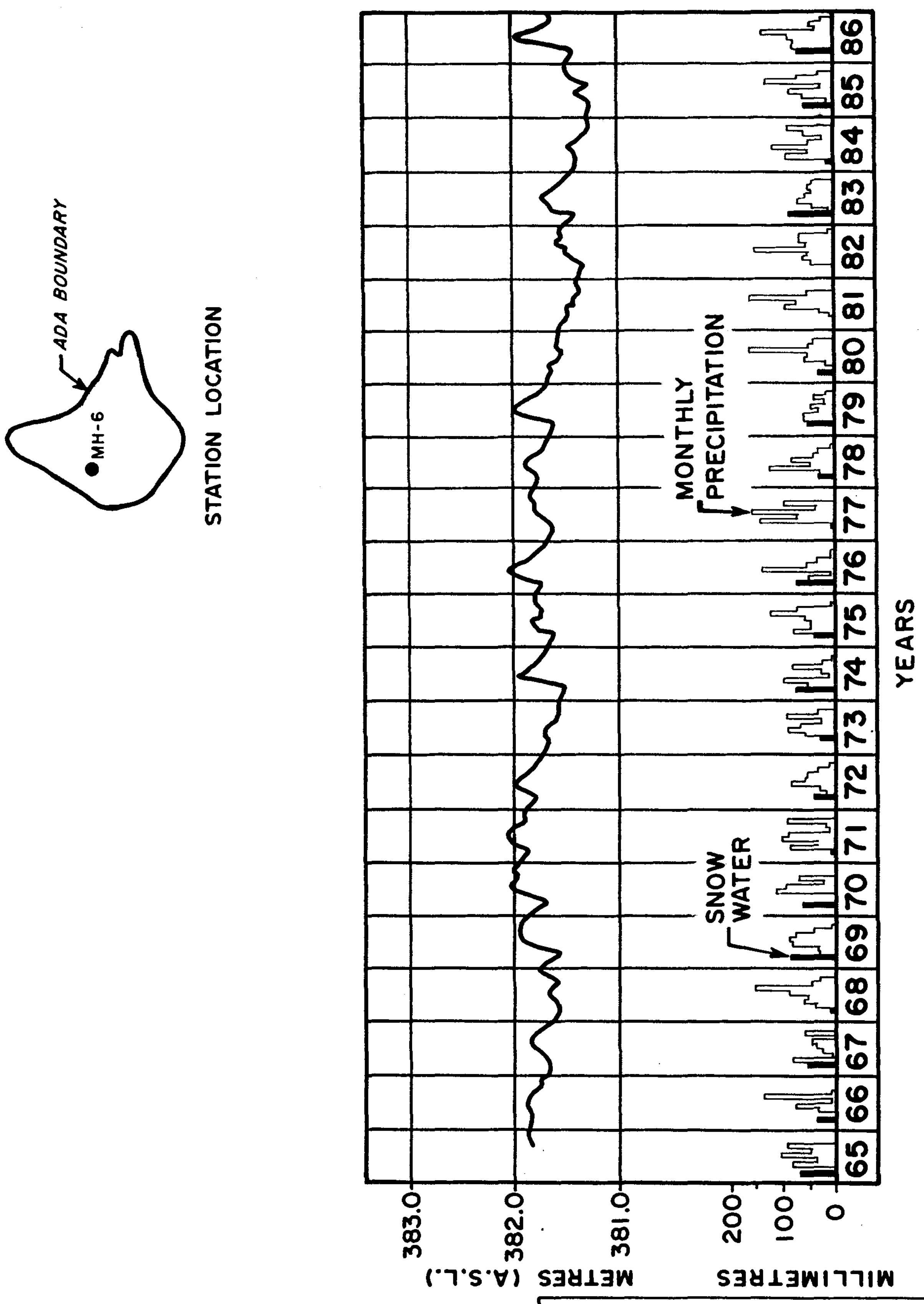


FIGURE 2

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

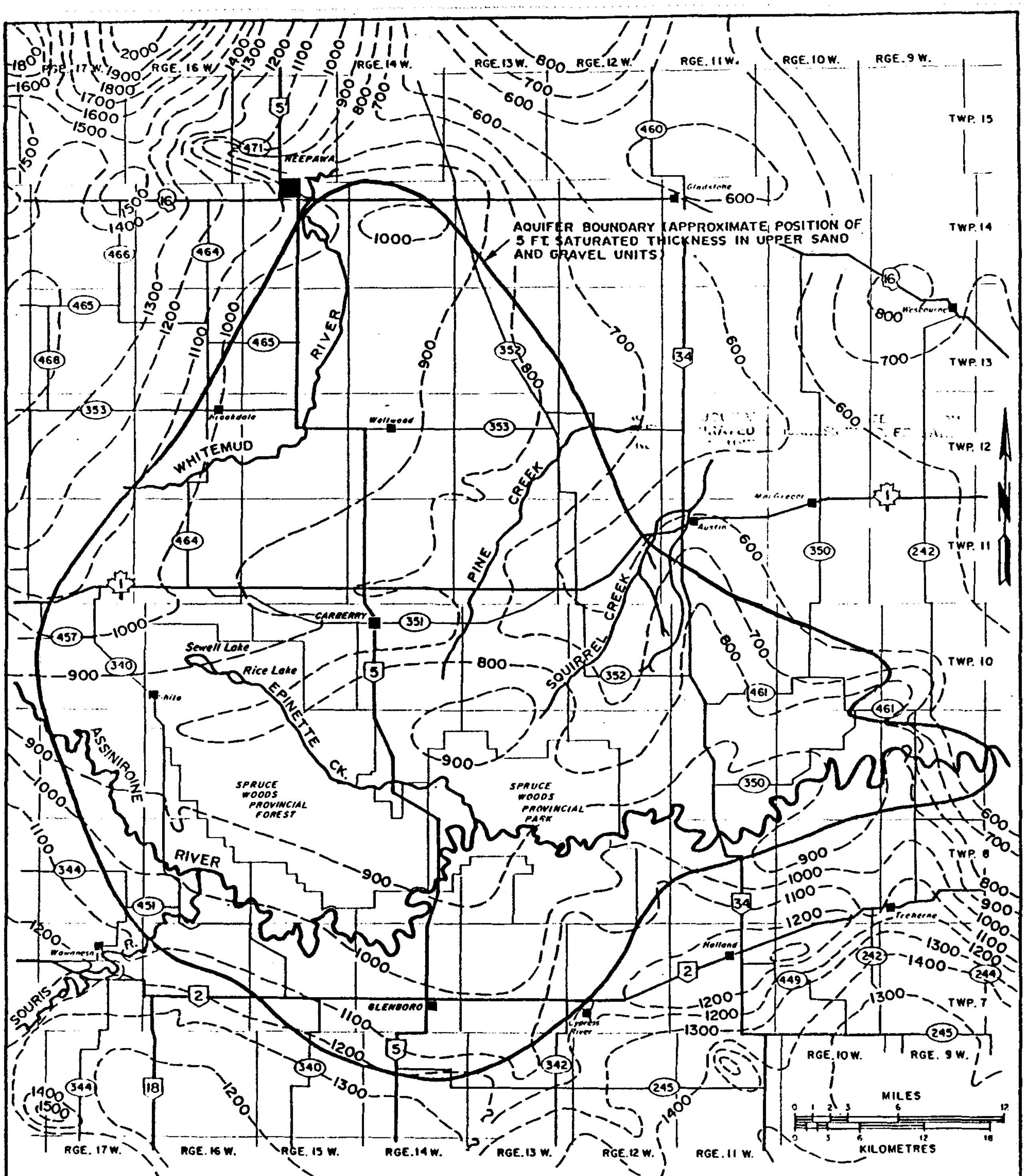
PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

ASSINIBOINE DELTA AQUIFER

HYDROGRAPH OF MH-6

DRAWN			
F.B.R.	Manitoba Natural Resources Water Resources		
CHECKED			
PREPARED F.W. Render	SUBMITTED [signature]	APPROVED [signature]	

SCALE	DATE	SHEET	FILE NO.
AS SHOWN	86 06 27	2 OF 88	90-1-7-1141



LEGEND

900 — BEDROCK CONTOUR (Contour Interval: 100 feet)

FIGURE 4

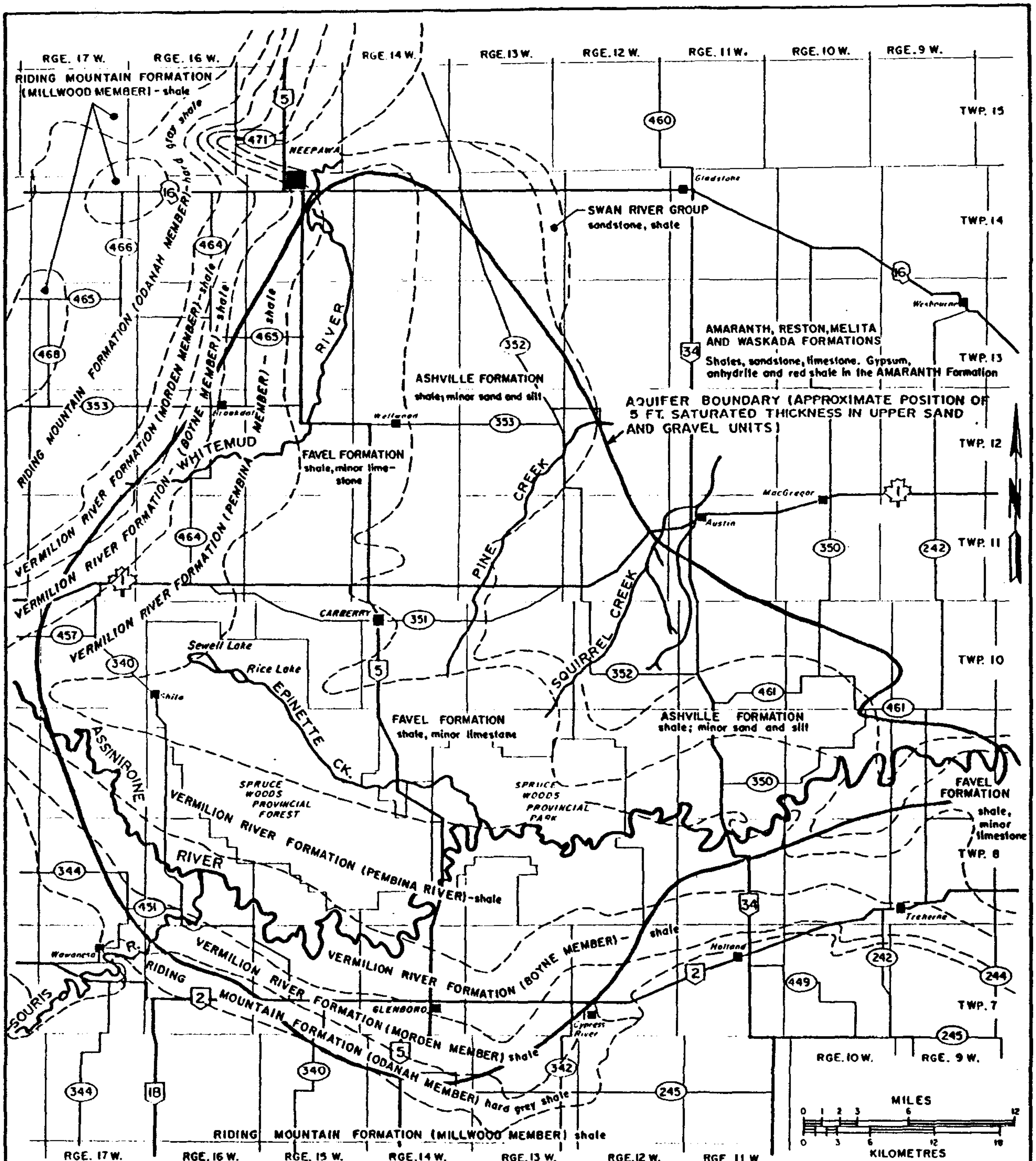
"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

ASSINIBOINE DELTA AQUIFER

BEDROCK SURFACE TOPOGRAPHY

Manitoba Natural Resources
Water Resources

DRAWN F.B.R.	CHECKED	PREPARED F.W. Render	SUBMITTED / APPROVED
SCALE AS SHOWN	DATE 86 06 27	SHEET 4 OF 88	FILE NO. 90-1-7-1141



NOTE: *ALL FORMATIONS ARE FROM THE MESOZOIC ERA*

LEGEND

– – – GEOLOGICAL CONTACT (FORMATION OR GROUP; MEMBER)

FIGURE 5

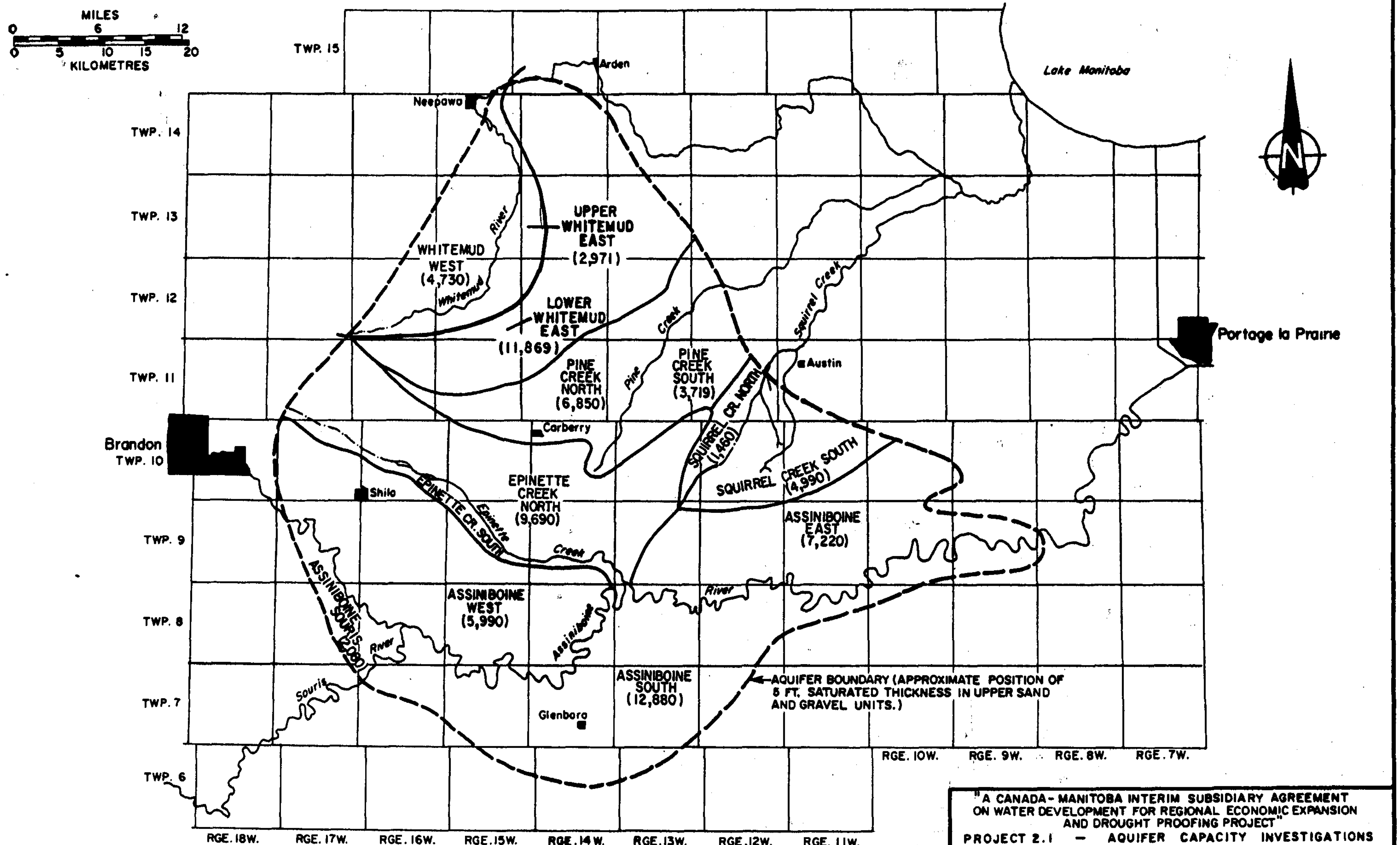
"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

ASSINIBOINE DELTA AQUIFER

BEDROCK SURFACE GEOLOGY

Manitoba Natural Resources
Water Resources

DRAWN	CHECKED	PREPARED	SUBMITTED	APPROVED	SCALE	DATE	SHEET	FILE NO.
F.B.R.		F.W. Render	[signature]	[signature]	AS SHOWN	86 06 27	5 OF 88	90-1-7-1141



LEGEND

- – – – AQUIFER BOUNDARY
- ——— AQUIFER SUB BASIN BOUNDARY
- (9,690) CAPACITY (ESTIMATE IN ACRE FEET OF WATER PER ANNUM)

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 — AQUIFER CAPACITY INVESTIGATIONS

PROVINCE OF MANITOBA
DEPARTMENT OF NATURAL RESOURCES
WATER RESOURCES BRANCH

ASSINIBOINE DELTA AQUIFER ESTIMATED SUB BASIN GROUNDWATER CAPACITY

DRAWN	CHECKED	PREPARED	SUBMITTED	APPROVED
R. R. PALKA		F. RENDER	[signature]	[signature]

SCALE	DATE	SHEET	FILE NO.
AS SHOWN	86 06 27	6 OF 88	90-1-7-1141

FIGURE 6

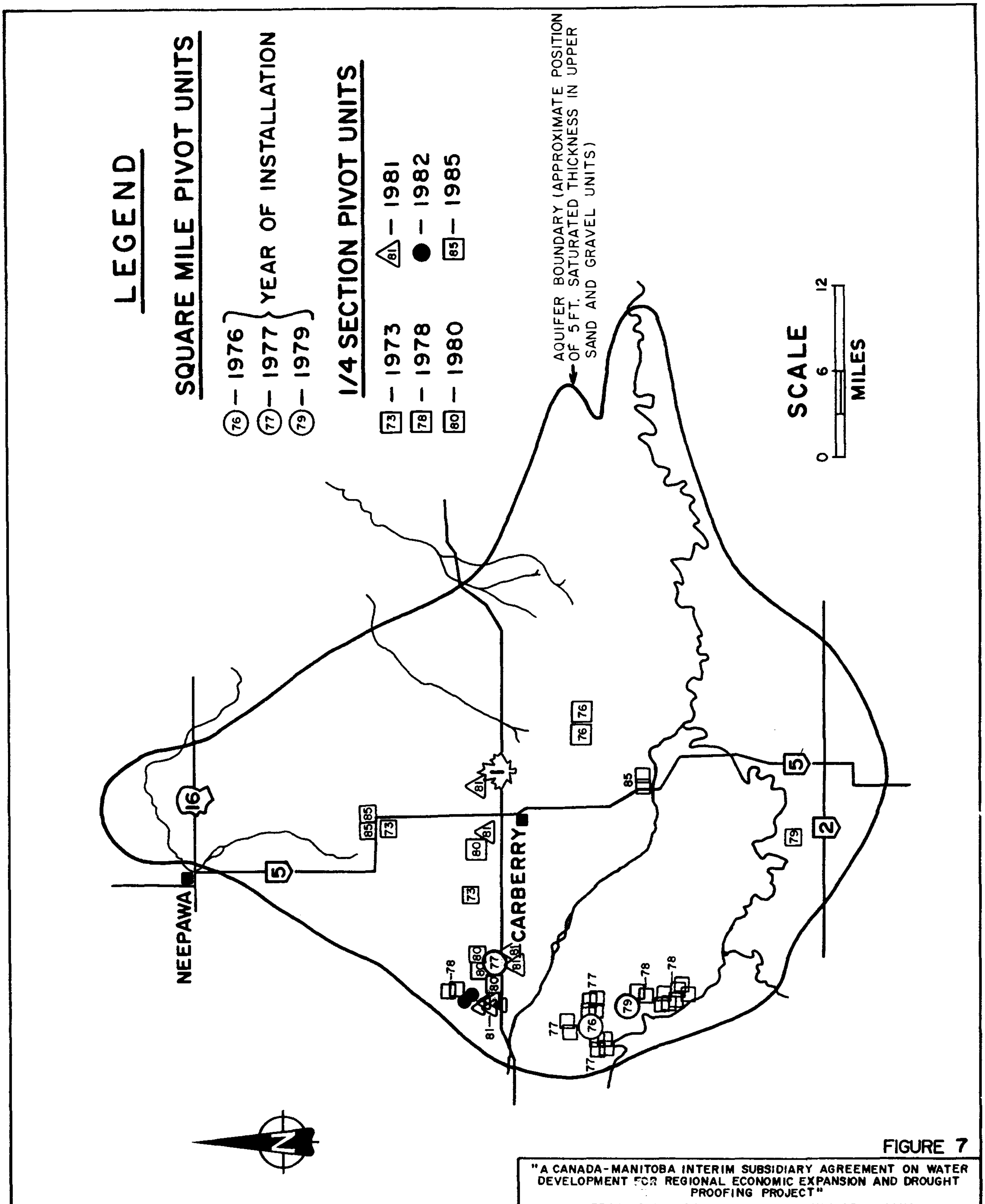


FIGURE 7

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

DRAWN F.B.R.	Manitoba Natural Resources Water Resources	ASSINIBOINE DELTA AQUIFER
CHECKED		**IRRIGATION UNITS**
PREPARED F.W. Render	SUBMITTED / APPROVED	SCALE AS SHOWN · DATE 86 06 27 · SHEET 7 OF 88 · FILE NO. 90-1-7-1141

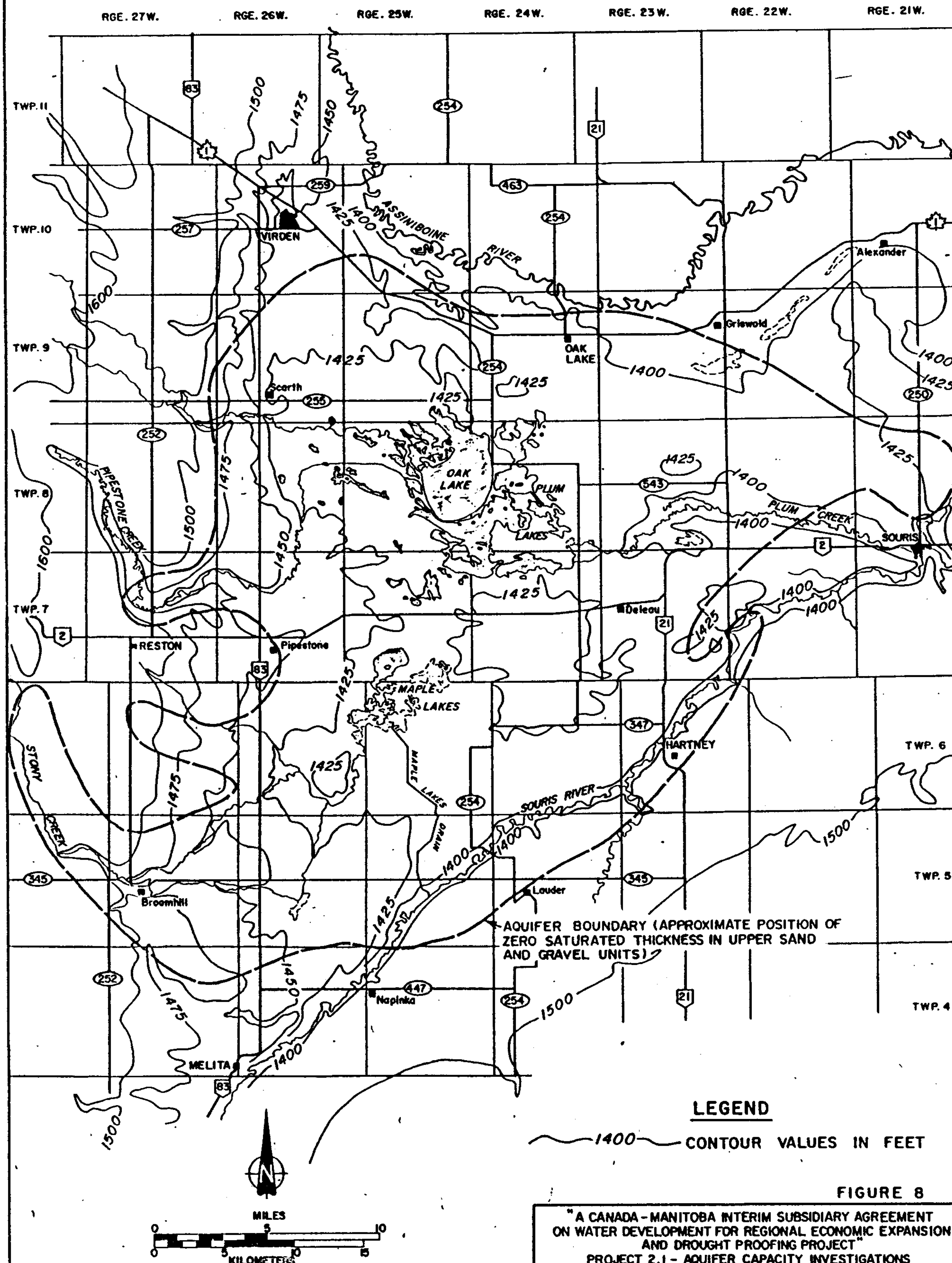


FIGURE 8

"A CANADA - MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

DRAWN F.B.R.	PROVINCE OF MANITOBA DEPARTMENT OF NATURAL RESOURCES WATER RESOURCES BRANCH		OAK LAKE AQUIFER **TOPOGRAPHY**			
CHECKED						
PREPARED F.W. Render	SUBMITTED	APPROVED	SCALE AS SHOWN	DATE 86 06 27	SHEET 8 OF 88	FILE No. 90-1-7-1141

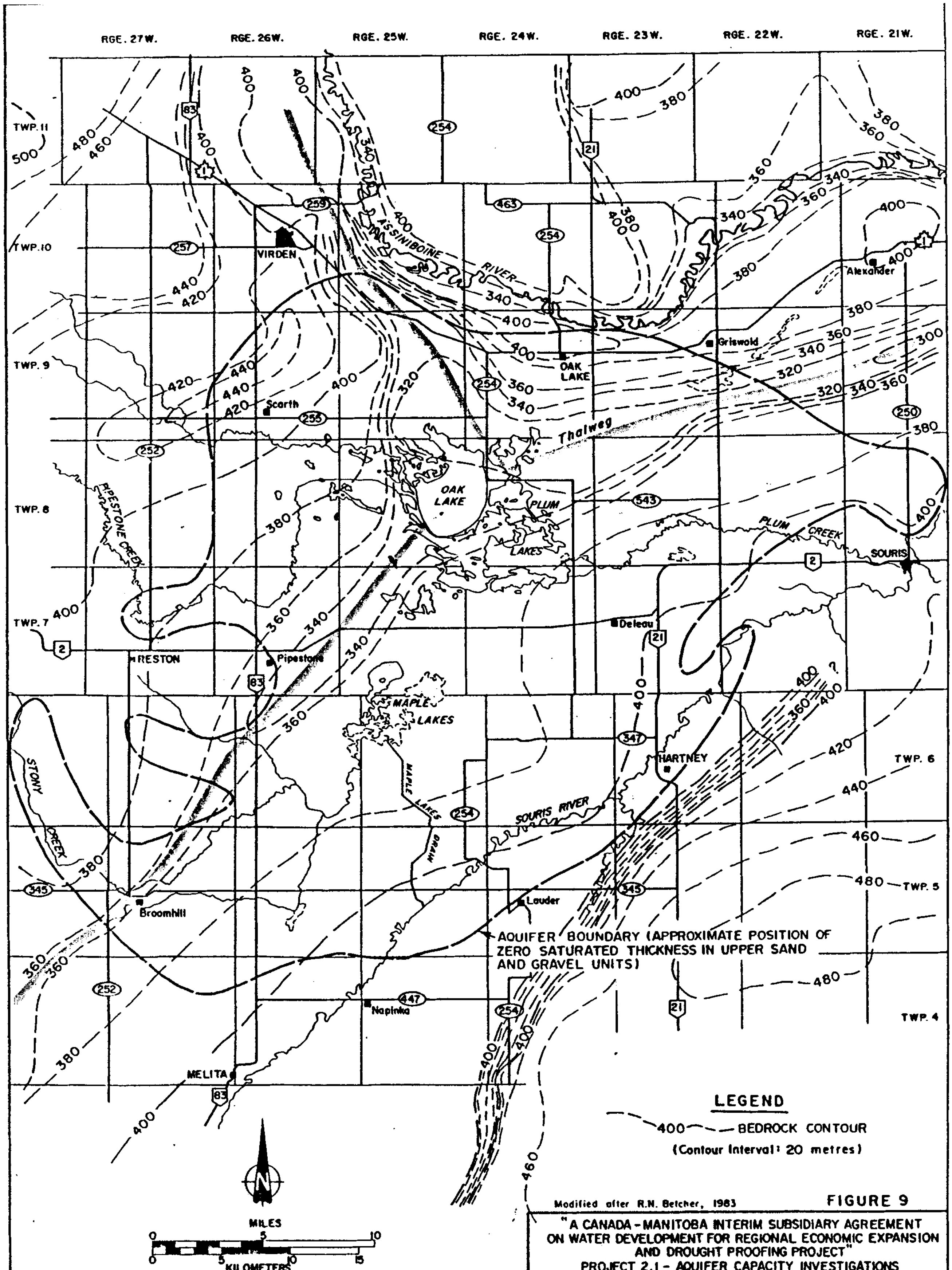


FIGURE 9

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

DRAWN F.B.R.

CHECKED

PREPARED F.W. Render

PROVINCE OF MANITOBA
DEPARTMENT OF NATURAL RESOURCES
WATER RESOURCES BRANCH

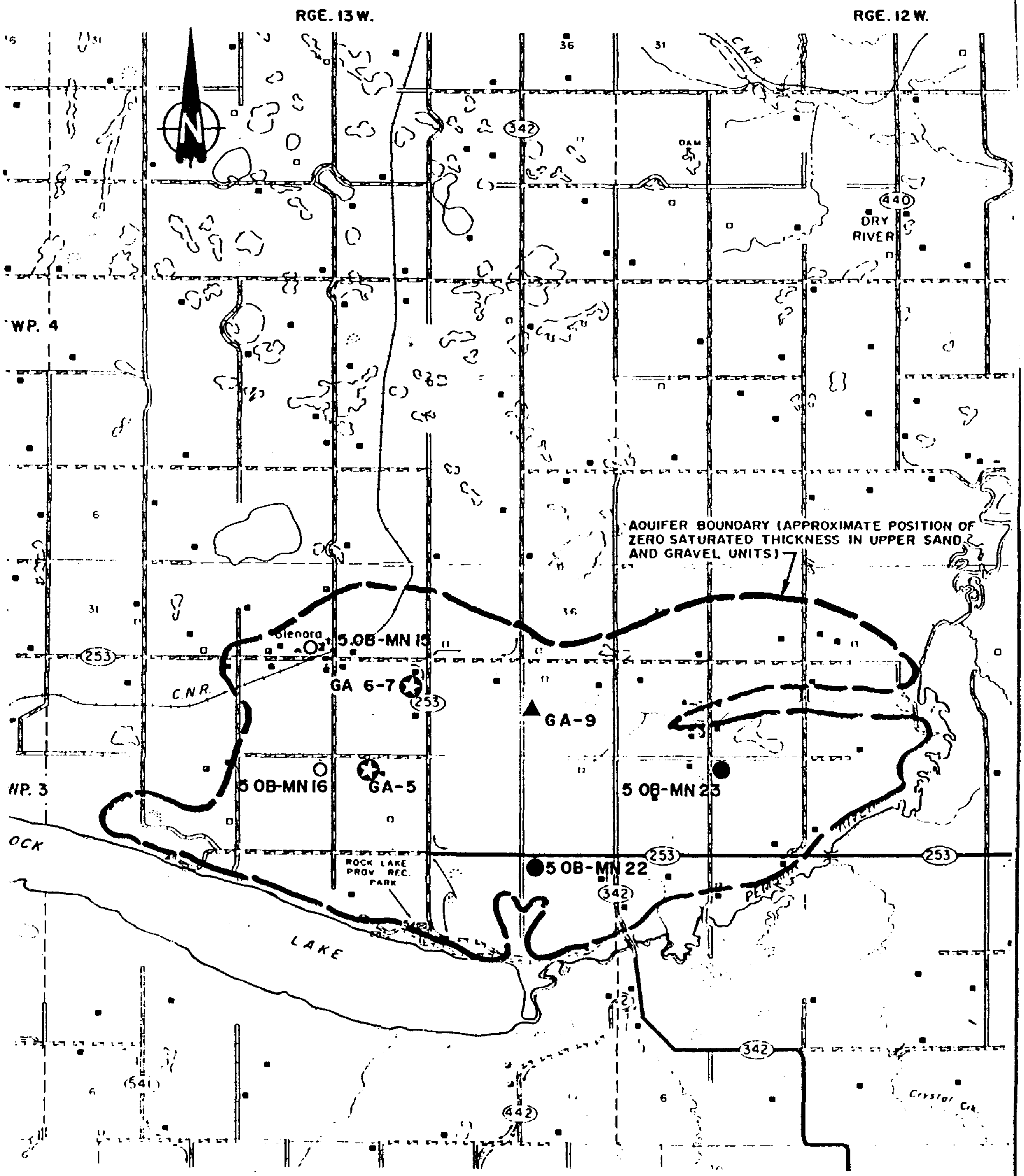
SUBMITTED

APPROVED

OAK LAKE AQUIFER

BEDROCK SURFACE TOPOGRAPHY

SCALE	DATE	SHEET	FILE No.
AS SHOWN	86 06 27	9 OF 88	90-1-7-1141



LEGEND:

- ● MONITORING STATION
- ▲ FORMAL PUMPING TEST SITE
- ✪ AUTOMATIC PUMPING TEST SITE
- ○ PRE-PROJECT MONITORING STATION

FIGURE 10

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1-AQUIFER CAPACITY INVESTIGATIONS

DRAWN M. M.	PROVINCE OF MANITOBA DEPARTMENT OF NATURAL RESOURCES **WATER RESOURCES BRANCH**	GLENORA AQUIFER **GROUNDWATER MONITORING STATIONS**
CHECKED	SUBMITTED [signature]	APPROVED [signature]
PREPARED W. H.	SCALE AS SHOWN / DATE 86 06 27	SHEET 10 OF 88 / FILE NO 90-1-7-1141

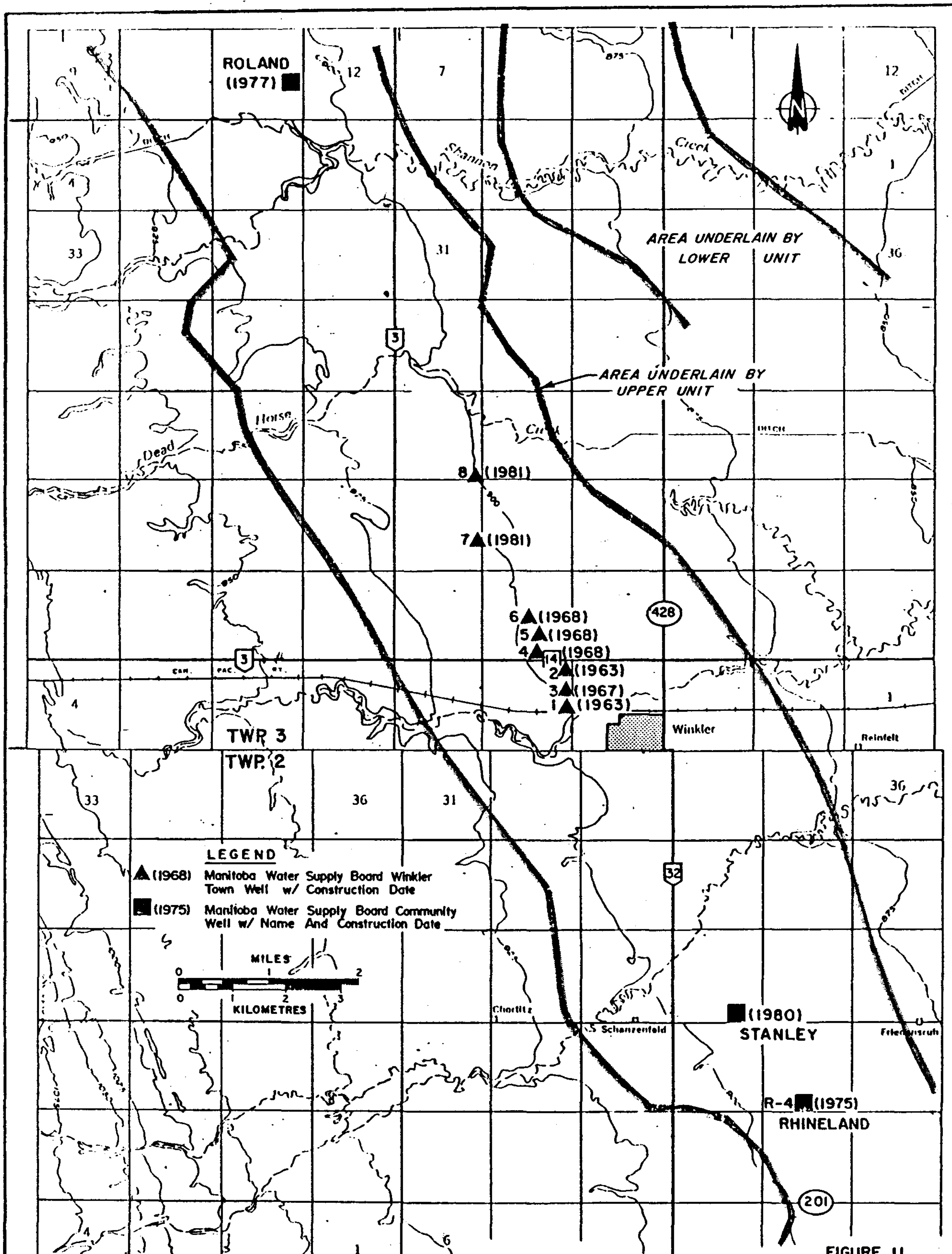


FIGURE 11

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

RGE. 5 W.

DRAWN F.B.R.	Manitoba Natural Resources Water Resources	WINKLER AQUIFER
CHECKED		**PRODUCTION WELLS**
PREPARED W. Hnydulk	SUBMITTED [signature] / APPROVED	SCALE AS SHOWN / DATE 86 06 27 / SHEET 11 OF 88 / FILE NO. 90-1-7-1141

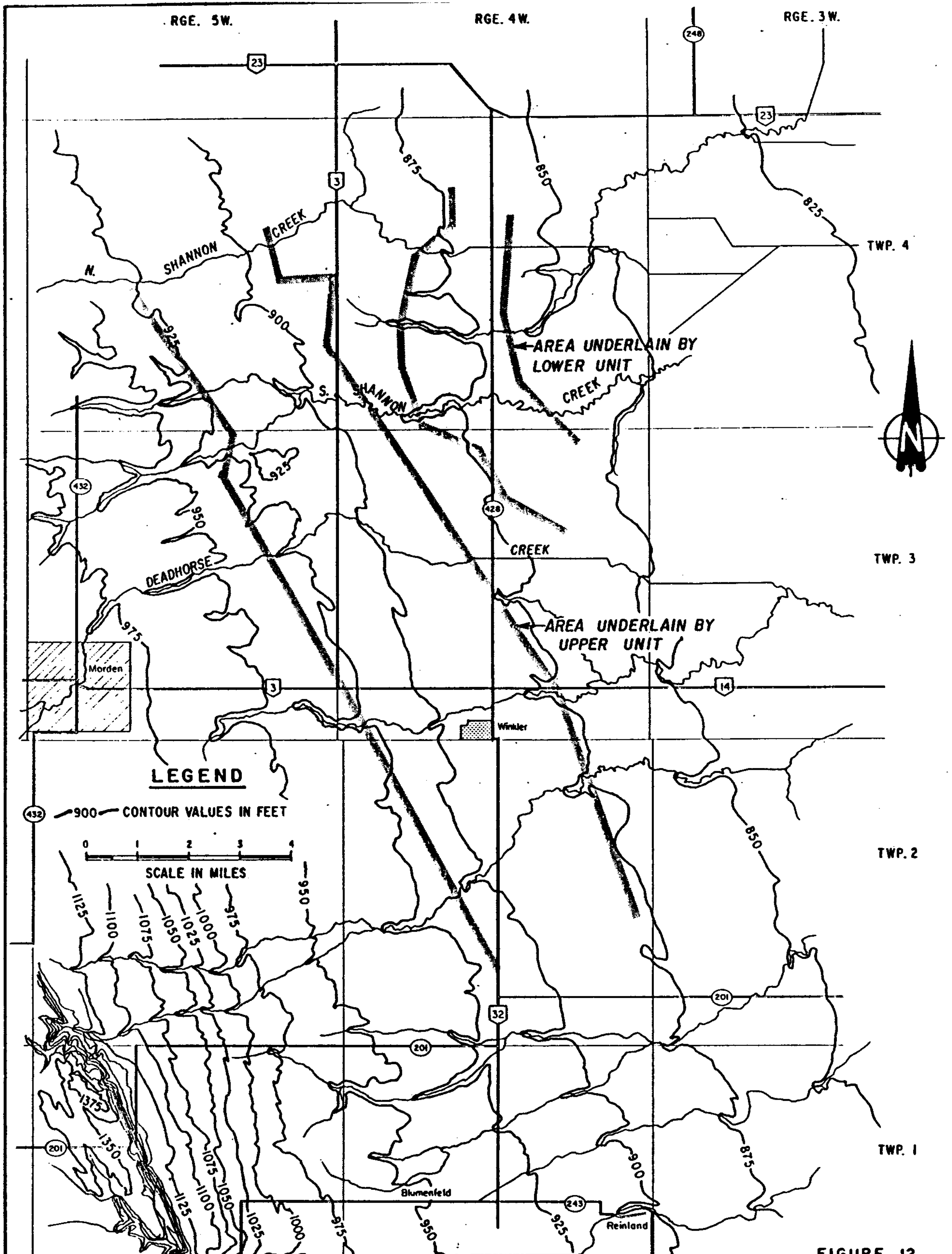


FIGURE 12

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

DRAWN F.B.R.	Manitoba Natural Resources Water Resources		WINKLER AQUIFER	
CHECKED			TOPOGRAPHY	
PREPARED F.W. Render	SUBMITTED [signature]	APPROVED		
SCALE AS SHOWN	DATE 86 06 27	SHEET 12 OF 88	FILE NO. 90-1-7-1141	

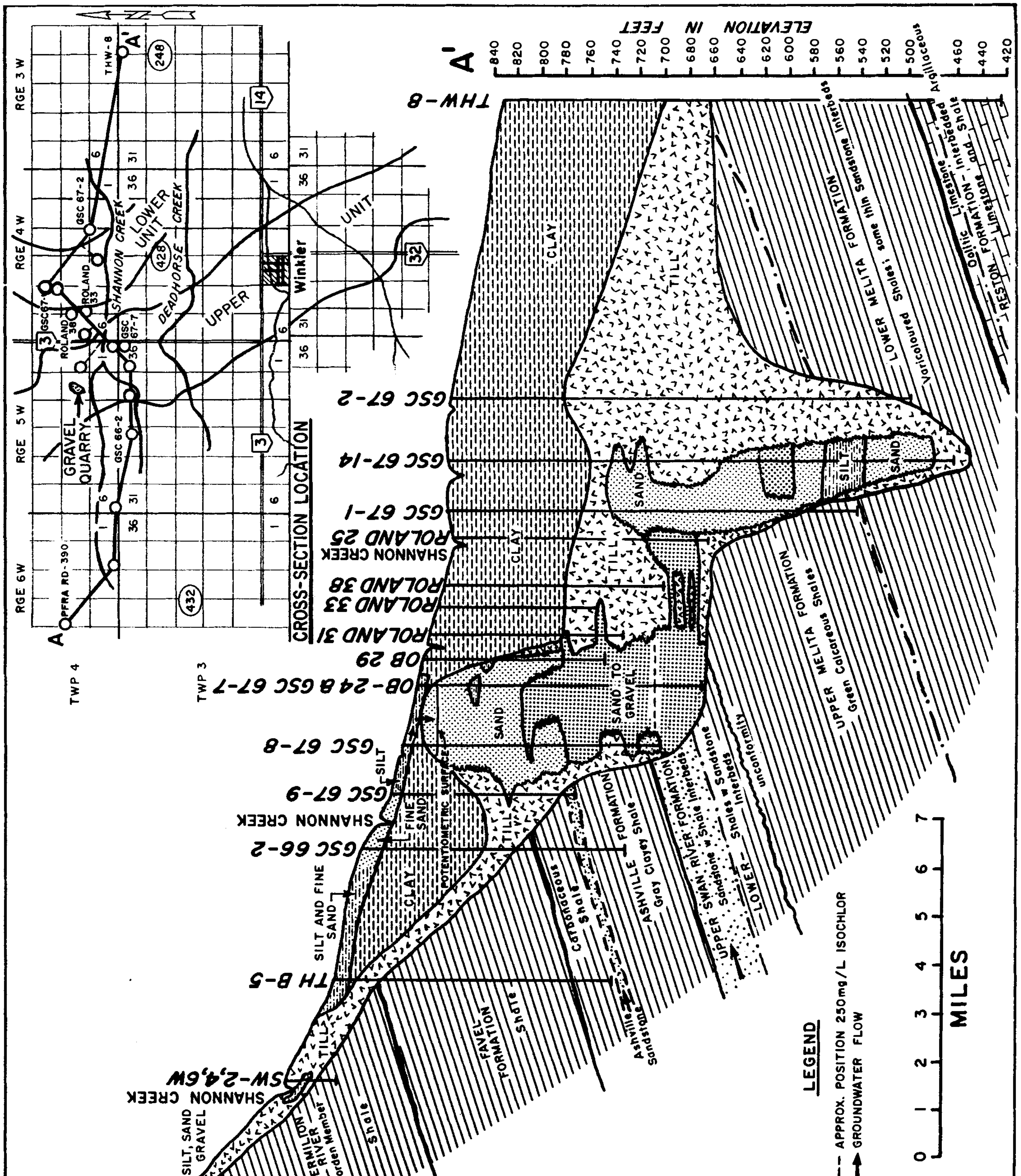


FIGURE 13

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

DRAWN F.B.R.	Manitoba Natural Resources Water Resources	WINKLER AQUIFER
CHECKED		HYDROGEOLOGIC CROSS-SECTION
PREPARED F.W. Render	SUBMITTED [signature] APPROVED [signature]	SCALE AS SHOWN; DATE 86 06 27; SHEET 13 OF 88; FILE NO. 90-1-7-1141

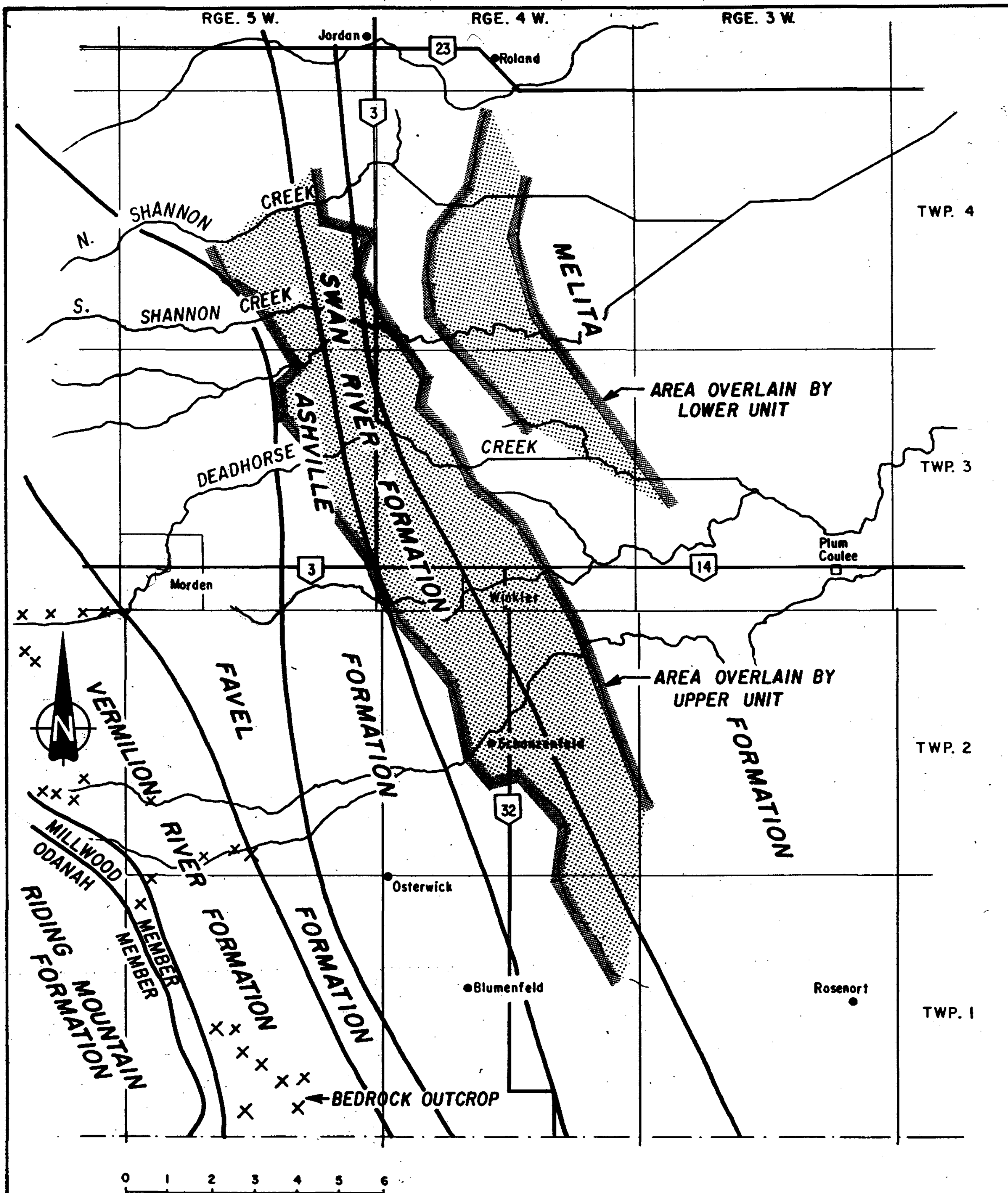


FIGURE 14

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

After: SIE and LITTLE, 1976 & 80

DRAWN F.B.R.	Manitoba Natural Resources Water Resources	WINKLER AQUIFER
CHECKED		BEDROCK GEOLOGY
PREPARED F.W. Render	SUBMITTED [signature] APPROVED [signature]	SCALE AS SHOWN · DATE 86 06 27 · SHEET 14 OF 88 · FILE NO. 90-1-7-1141

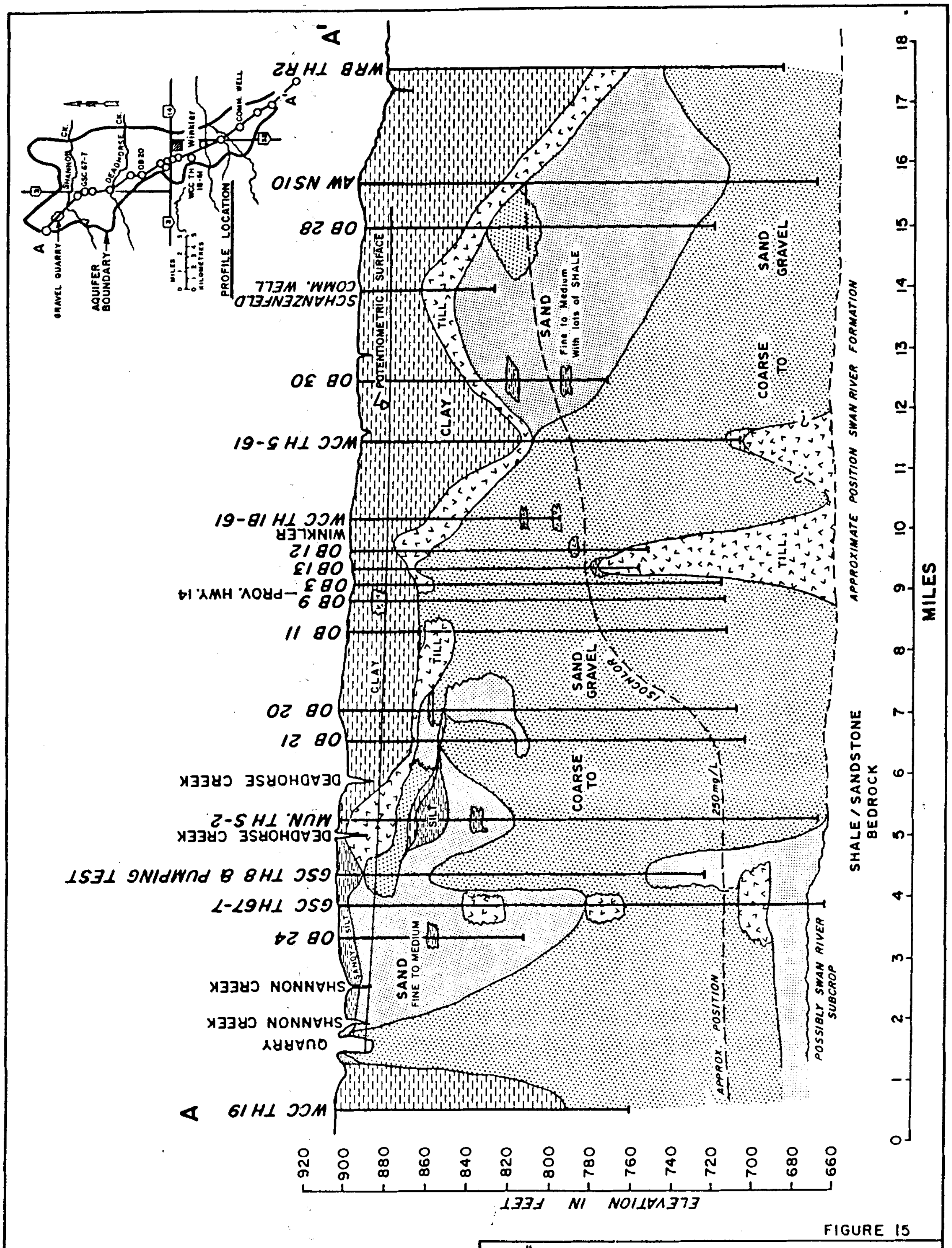


FIGURE 15

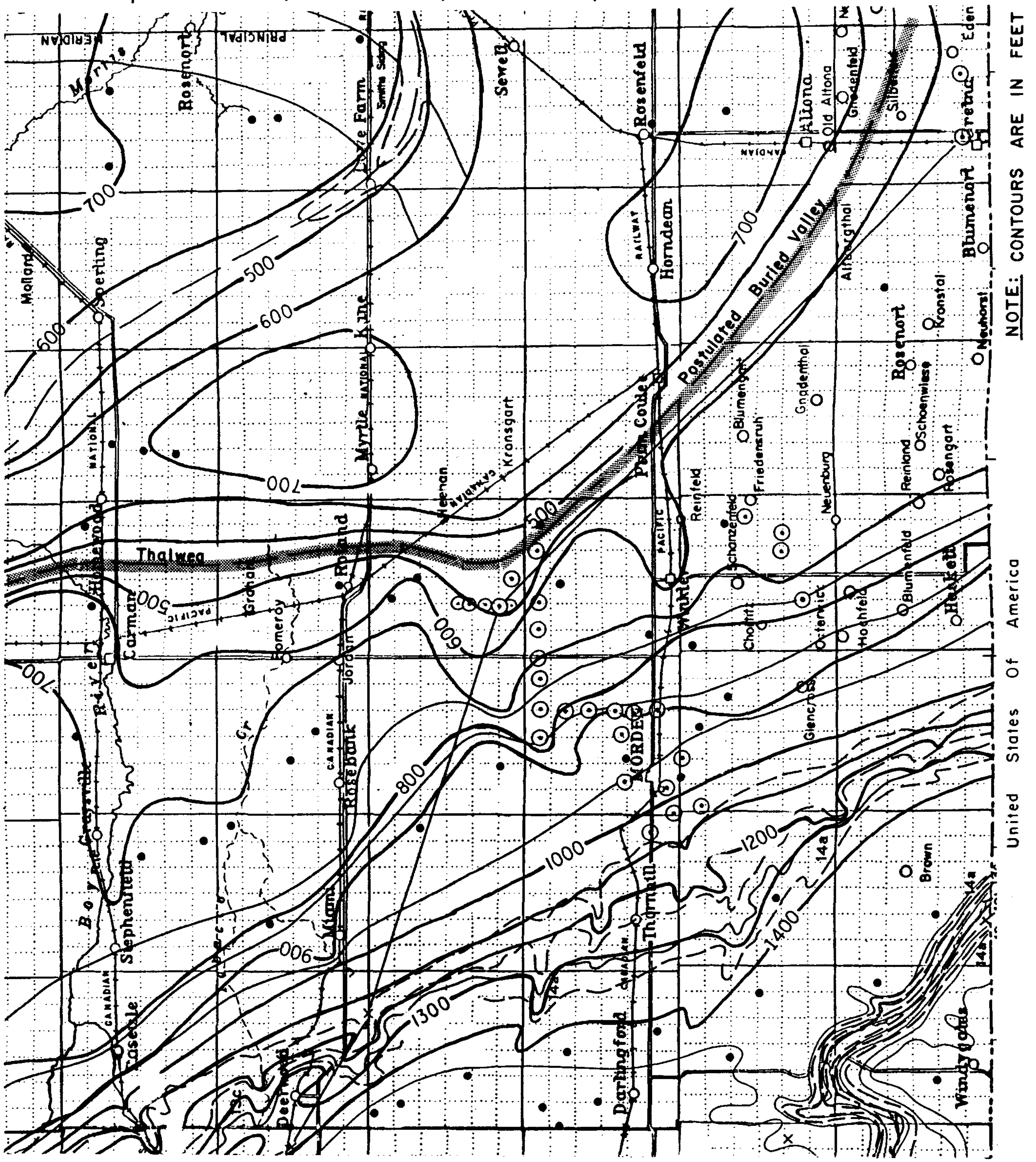
"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

WINKLER AQUIFER

HYDROGEOLOGIC PROFILE

Manitoba Natural Resources
Water Resources

DRAWN	CHECKED	PREPARED	SUBMITTED	APPROVED	SCALE	DATE	SHEET	FILE NO.
F.B.R.		W.H. / F.W.R.	[signature]		AS SHOWN	86 06 27	15 OF 88	90-1-7-1141



After: KLASSEN R.W. et al, 1970

FIGURE 16

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

DRAWN F.B.R.	Manitoba Natural Resources Water Resources	WINKLER AQUIFER
CHECKED		BEDROCK SURFACE TOPOGRAPHY
PREPARED F.W. Render	SUBMITTED [signature] APPROVED [signature]	SCALE AS SHOWN · DATE 86 06 27 · SHEET 16 OF 88 · FILE NO. 90-1-7-1141

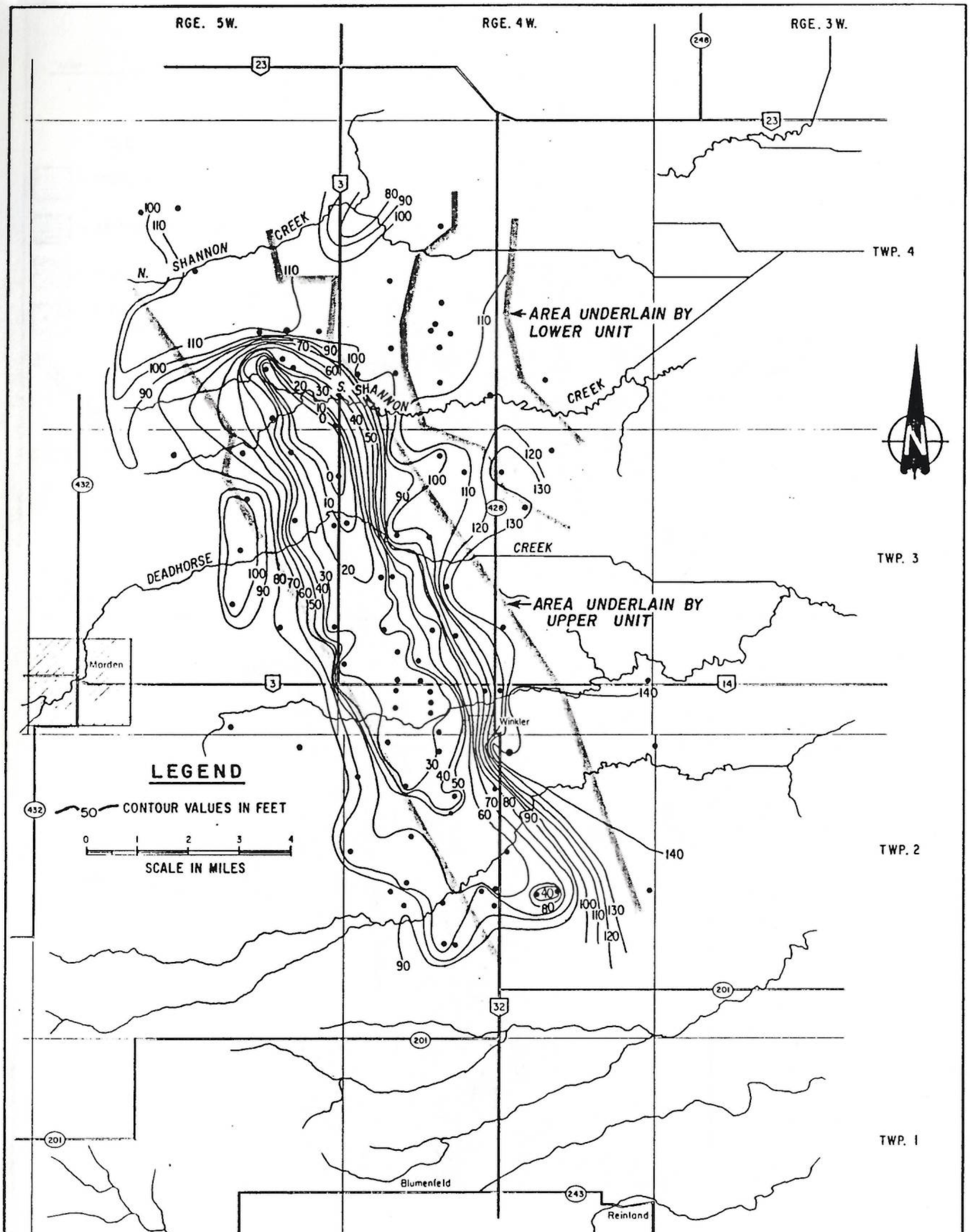


FIGURE 17

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 – AQUIFER CAPACITY INVESTIGATIONS

DRAWN F.B.R.	Manitoba Natural Resources Water Resources	WINKLER AQUIFER		
CHECKED		**CLAY THICKNESS**		
PREPARED W.H./F.W.R.	SUBMITTED [signature] / APPROVED [signature]	SCALE AS SHOWN	DATE 86 06 27	SHEET 17 OF 88
		FILE NO. 90-1-7-1141		

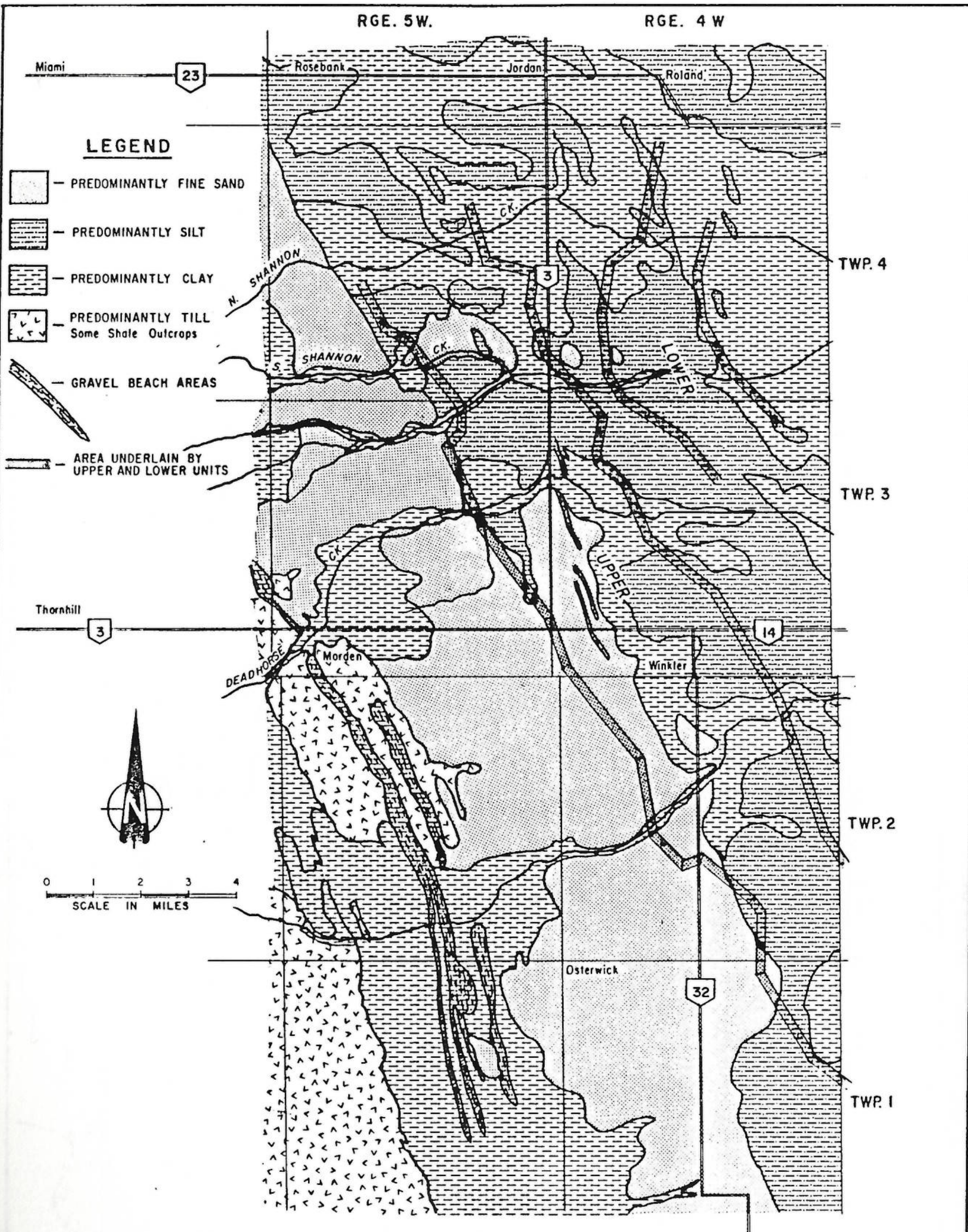


FIGURE 18

"A CANADA–MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 – AQUIFER CAPACITY INVESTIGATIONS

After: ELLIS and SHAFER, 1943

DRAWN F.B.R.	Manitoba Natural Resources Water Resources	WINKLER AQUIFER
CHECKED		SURFACE DEPOSITS
PREPARED F.W. Render	SUBMITTED [signature] APPROVED [signature]	SCALE AS SHOWN · DATE 86 06 27 · SHEET 18 OF 88 · FILE NO. 90-1-7-1141

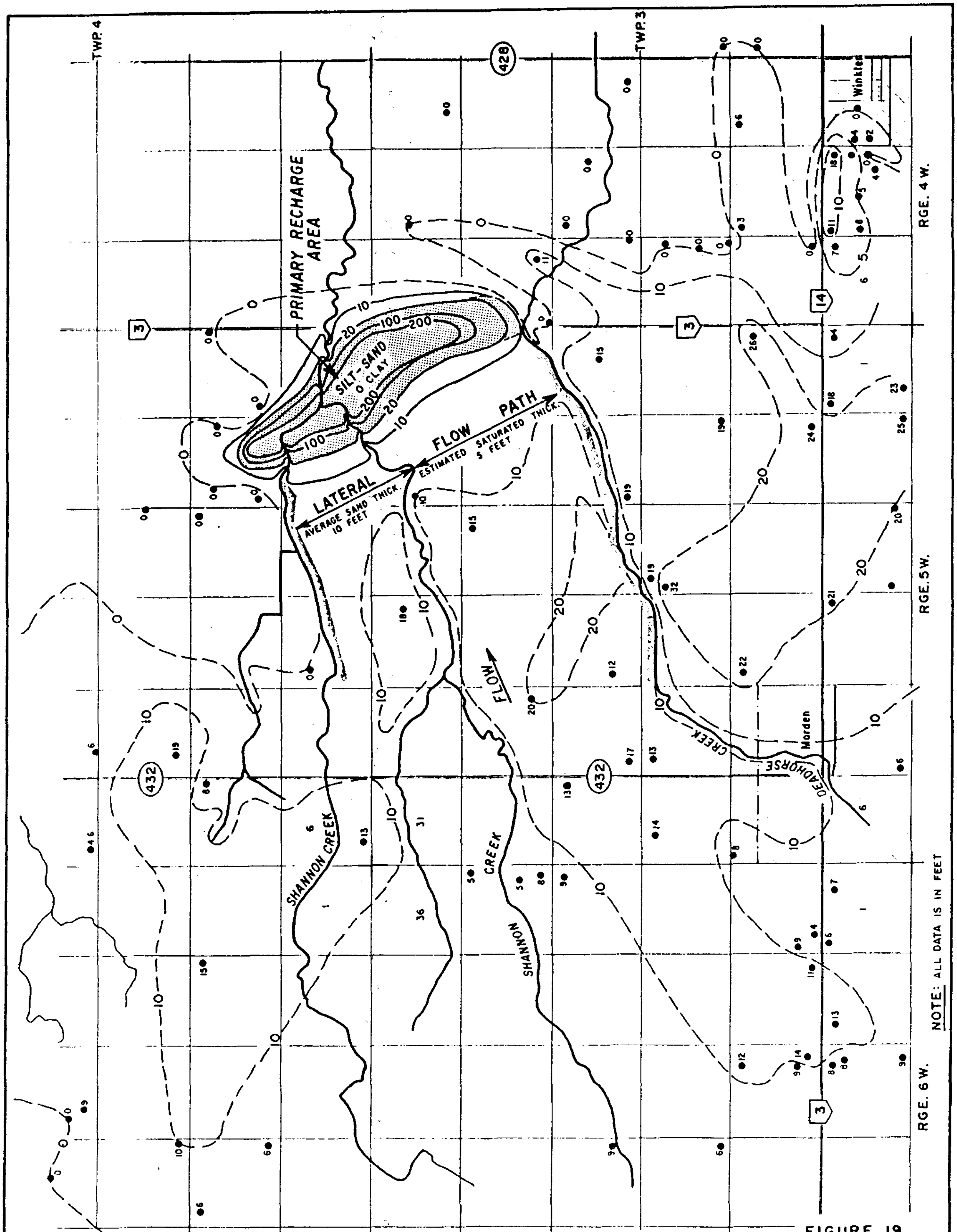


FIGURE 19

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

DRAWN F.B.R.	**Manitoba Natural Resources** Water Resources	WINKLER AQUIFER
CHECKED		LATERAL RECHARGE SOURCE AREA
PREPARED W.H./F.W.R.	SUBMITTED / APPROVED	**SURFICIAL SAND-SILT THICKNESS**

SCALE	DATE	SHEET	FILE NO.
AS SHOWN	86 06 27	19 OF 88	90-1-7-1141

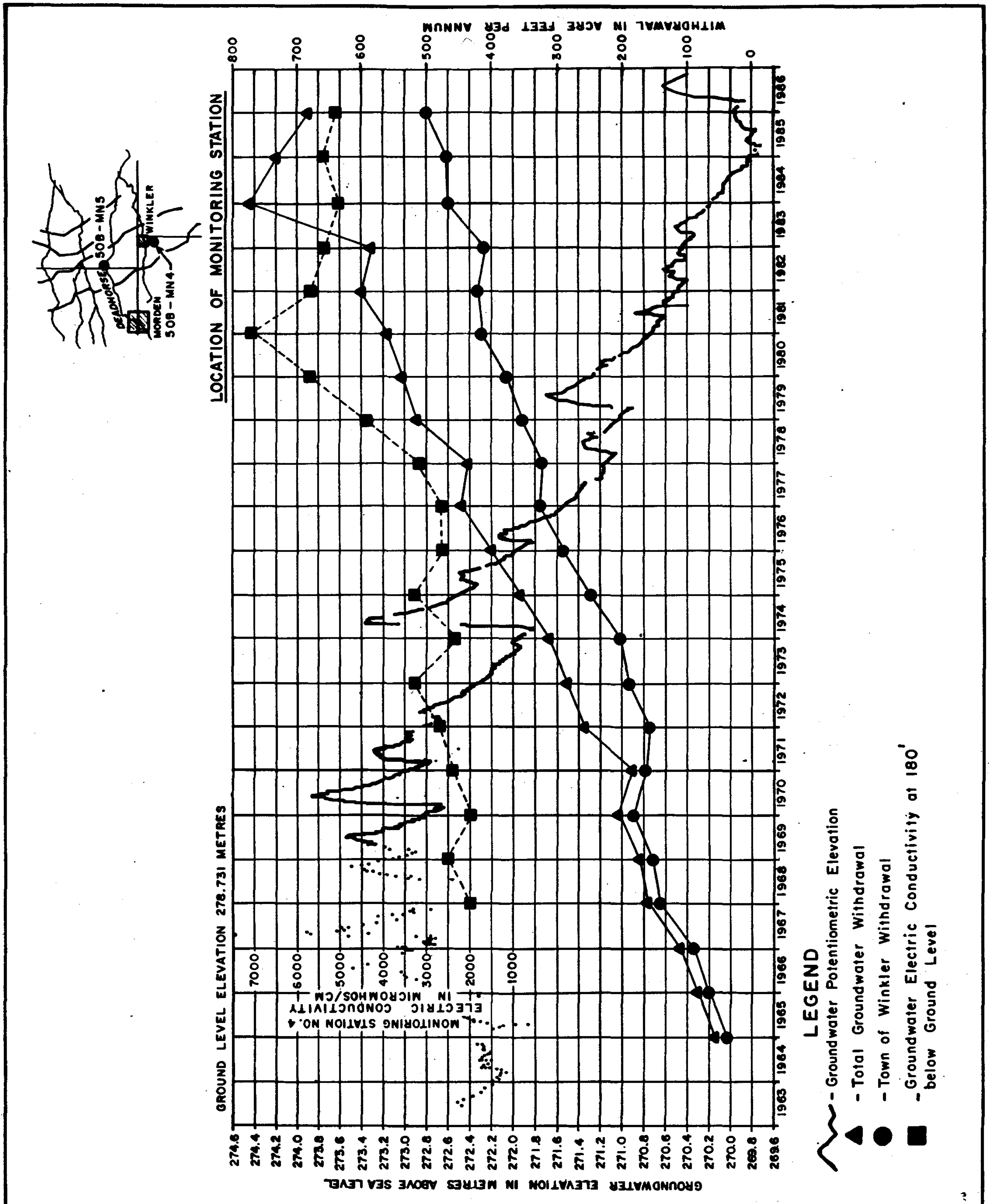
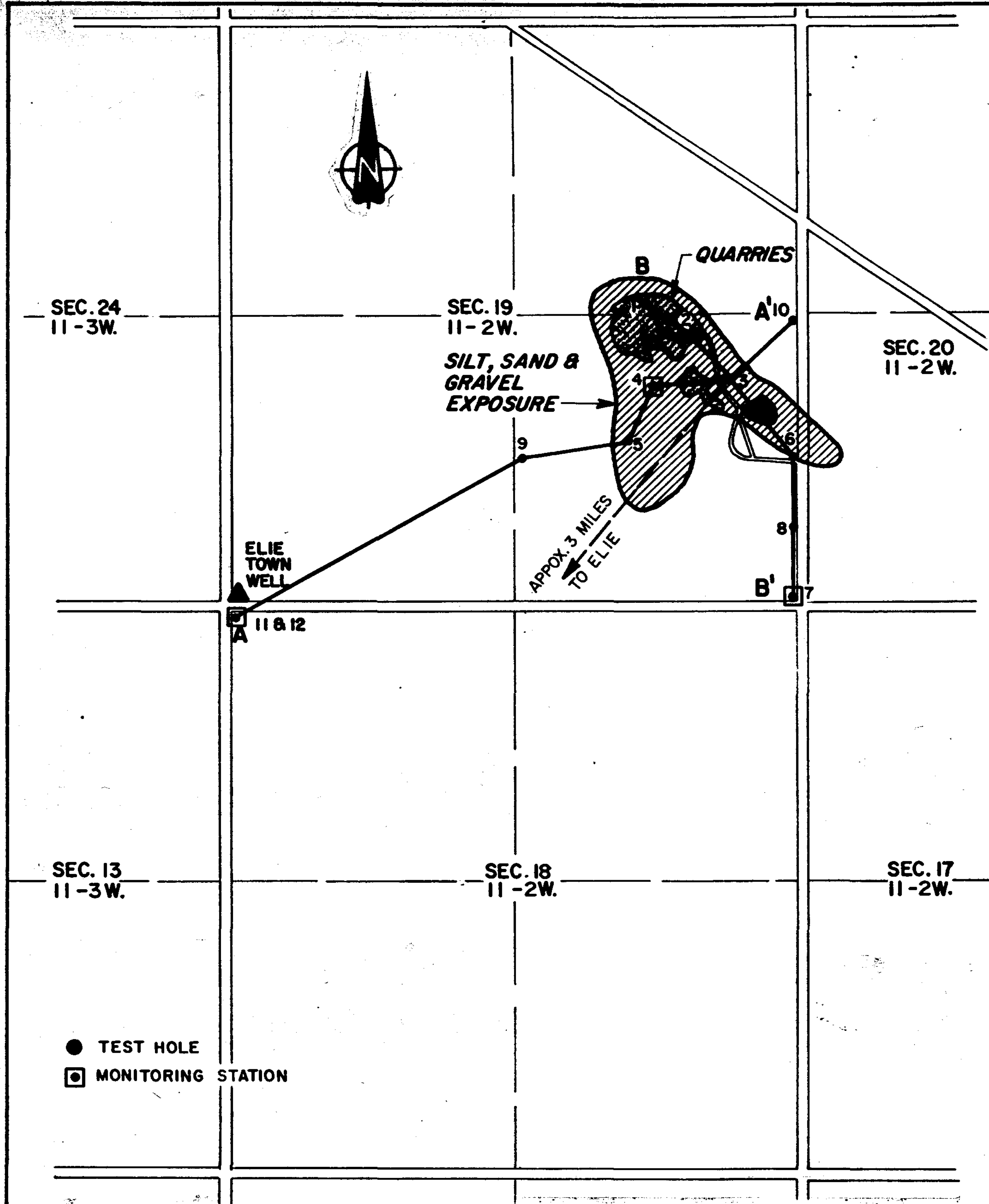


FIGURE 20

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

DRAWN	Manitoba Natural Resources Water Resources	WINKLER AQUIFER
F.B.R.		**HYDROGRAPHS FOR MONITORING STATIONS 4&5**
CHECKED		
PREPARED F.W. Render	SUBMITTED [signature] APPROVED [signature]	SCALE AS SHOWN / DATE 86 06 27 / SHEET 20 OF 88 / FILE NO. 90-1-7-1141



0 500 1500 2500

SCALE IN FEET

FIGURE 21

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

PROVINCE OF MANITOBA

DEPARTMENT OF NATURAL RESOURCES

WATER RESOURCES BRANCH

ELIE AQUIFER

TEST HOLES AND MONITORING STATIONS

PREPARED F.W. RENDER	DRAWN F.B.R. CHECKED	SUBMITTED	APPROVED	SCALE AS SHOWN	DATE 86 06 27	SHEET 21 OF 88	FILE NO. 90-1-7-1141

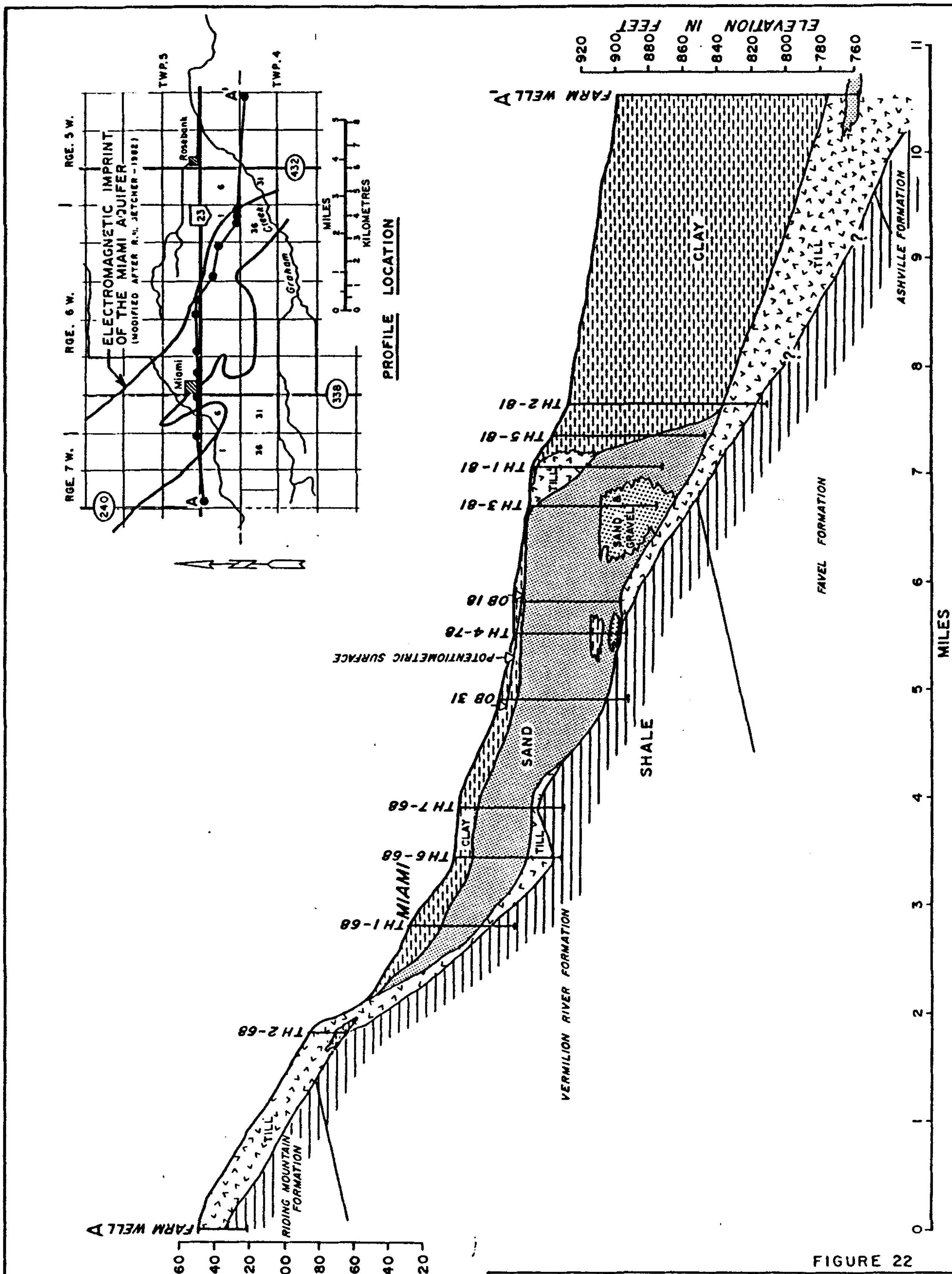


FIGURE 22

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

MIAMI AQUIFER

HYDROGEOLOGIC PROFILE

DRAWN F.B.R.	Manitoba Natural Resources Water Resources	
CHECKED		
PREPARED W.H./F.W.R.	SUBMITTED	APPROVED

SCALE	DATE	SHEET	FILE NO.
AS SHOWN	86 06 27	22 OF 88	90-1-7-1141

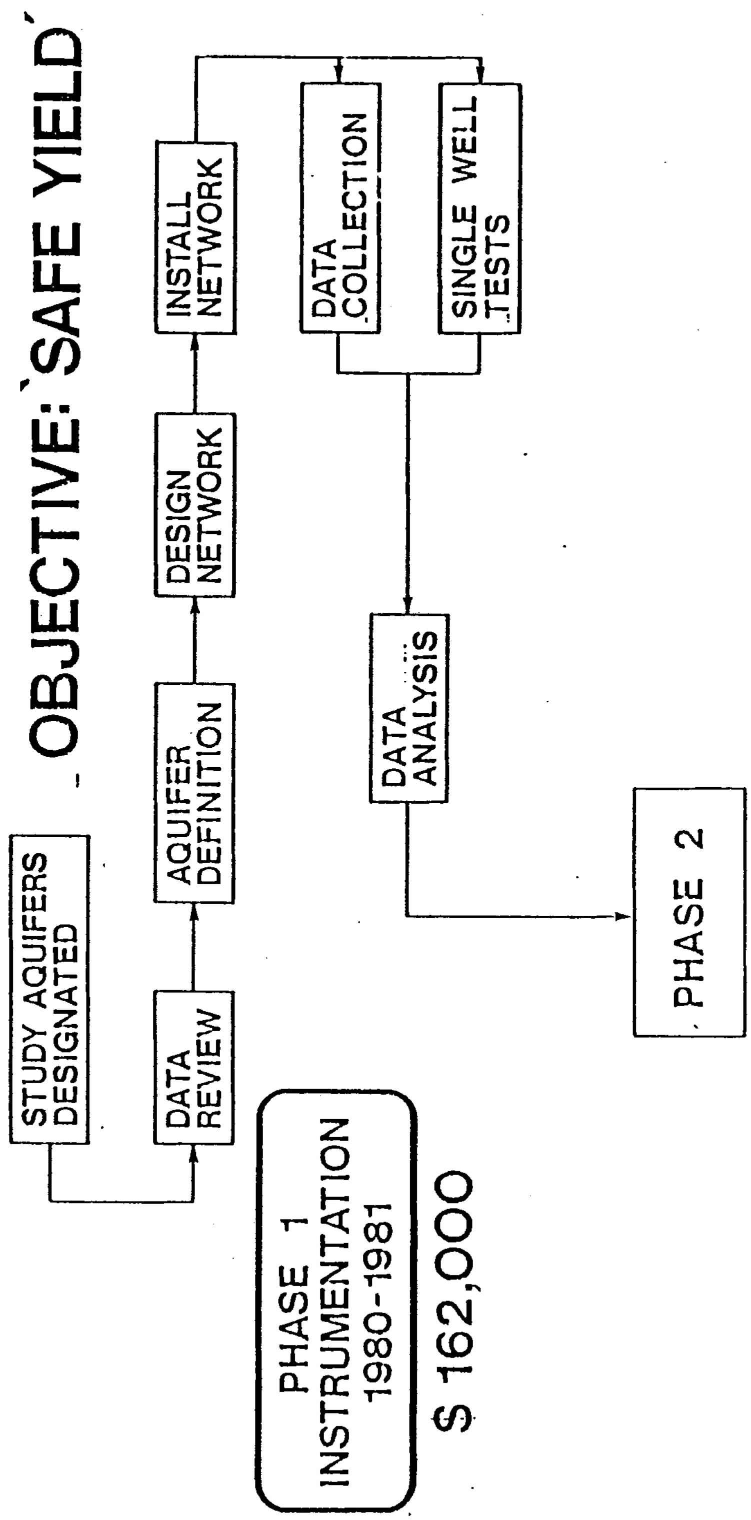


FIGURE 23

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

DRAWN F.B.R.	Manitoba Natural Resources Water Resources	**AQUIFER CAPACITY INVESTIGATION PHASE I**
CHECKED		
PREPARED F.W. Render	SUBMITTED [signature] / APPROVED [signature]	SCALE AS SHOWN / DATE 860627 / SHEET 23 OF 88 / FILE NO. 90-1-7-1141

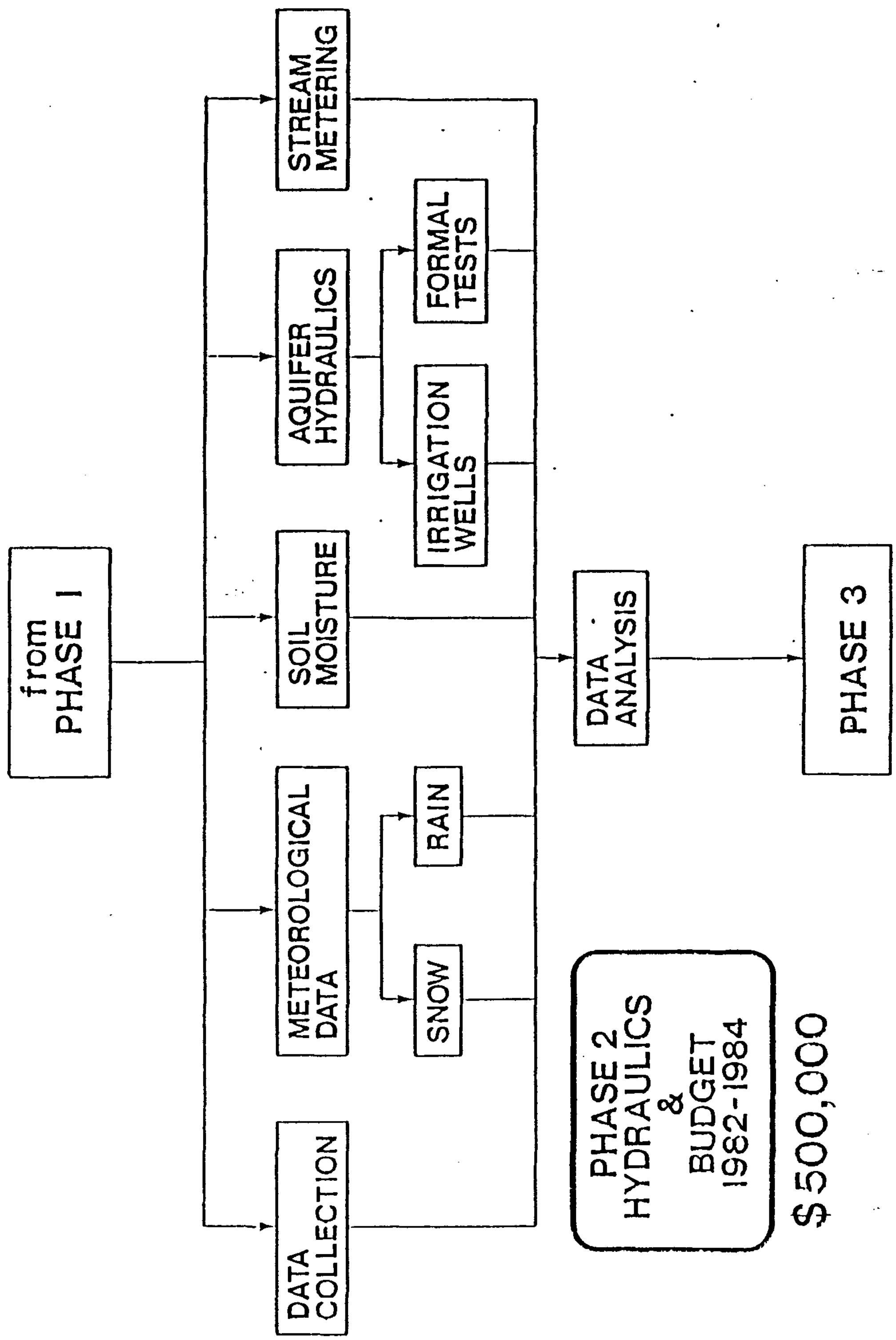


FIGURE 24

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

DRAWN F.B.R.	Manitoba Natural Resources	**AQUIFER CAPACITY INVESTIGATION PHASE 2**
CHECKED	Water Resources	
PREPARED F.W. Render	SUBMITTED / APPROVED	SCALE AS SHOWN · DATE 86 06 27 · SHEET 24 OF 88 · FILE NO. 90-1-7-1141

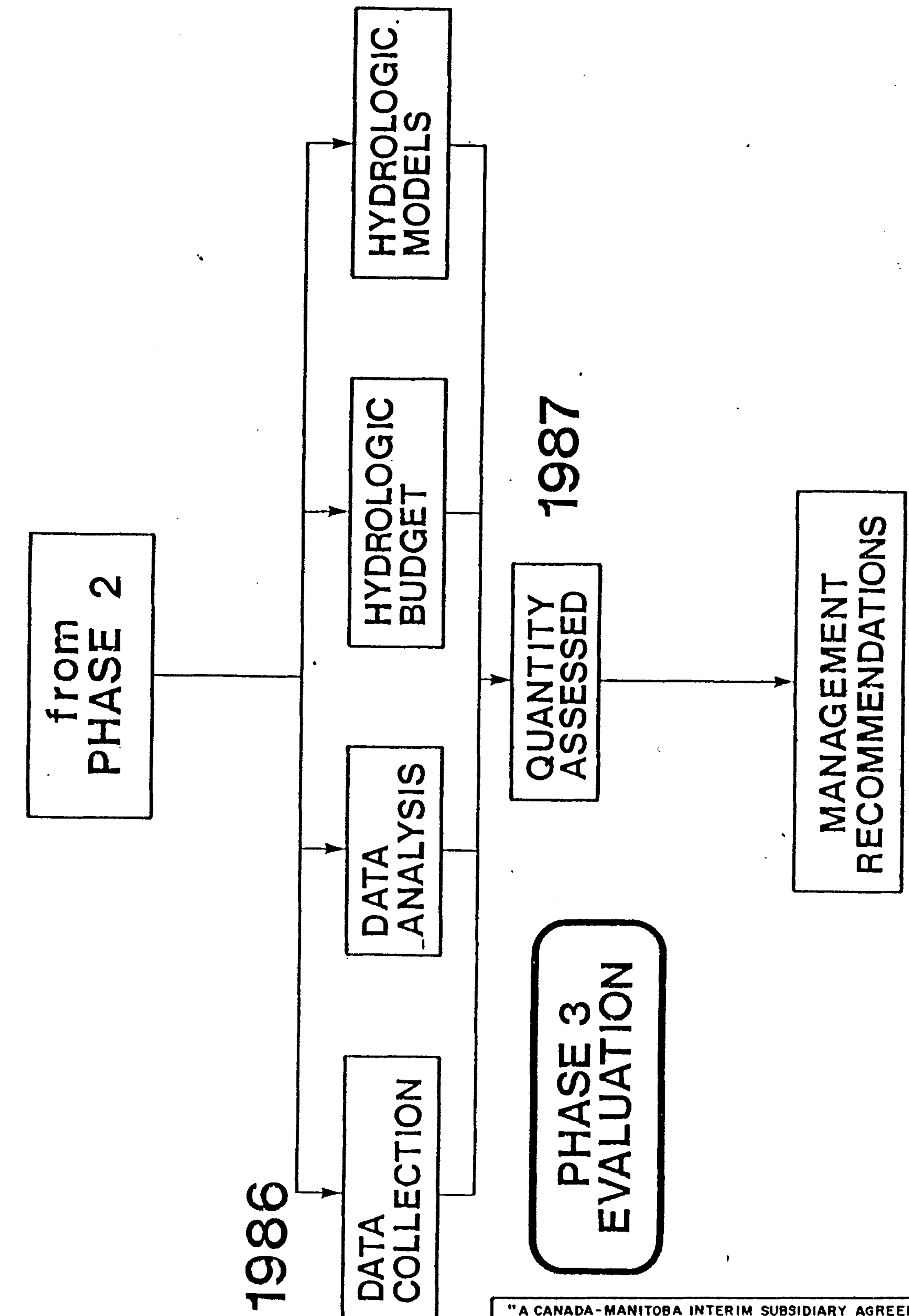


FIGURE 25

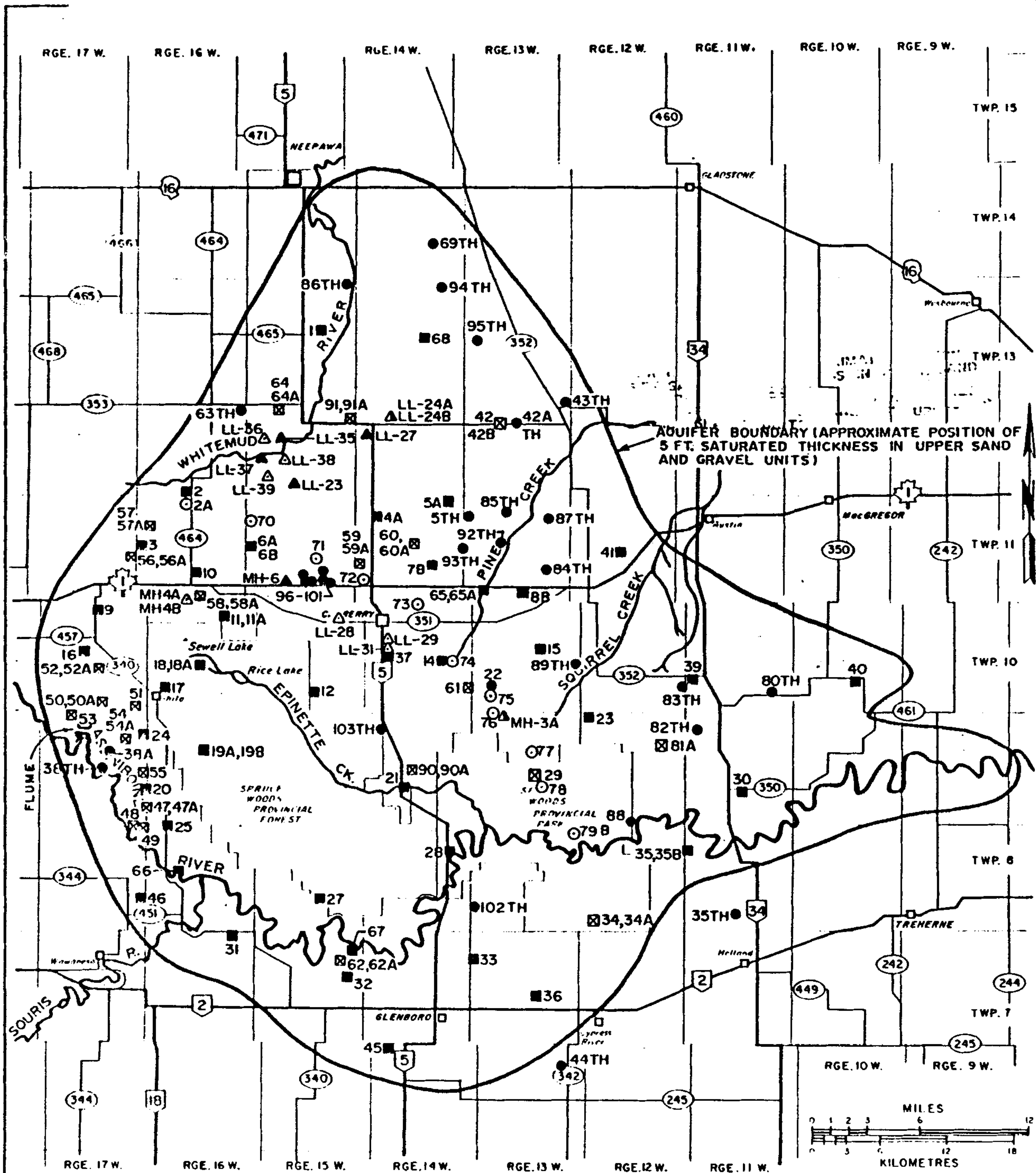
"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

Manitoba Natural Resources
Water Resources

AQUIFER CAPACITY INVESTIGATION PHASE 3

DRAWN	F.B.R.
CHECKED	
PREPARED	F.W. Render
SUBMITTED	[signature]
APPROVED	[signature]
SCALE	AS SHOWN
DATE	86 06 27
SHEET	25 OF 88
FILE NO.	90-1-7-1141



LEGEND

PRE PROJECT

- △ ONE OR MORE 2" WELLS
- ▲ ONE RECORDER WELL
- ▲ ONE RECORDER WELL & ONE 2" WELL

PROJECT

- ⊠ PUMPING TEST SITE
- ● 41 FIVE INCH DIAMETER MONITORING STATION WITH FIELD NUMBER
- ● 44 TH TEST HOLE WITH FIELD NUMBER
- ■ 42 / 42 B DEEP AND SHALLOW RECORDING 5" DIAMETER MONITORING STATION WITH FIELD NUMBERS
- ■ 8 RECORDING 5" DIAMETER MONITORING STATION WITH FIELD NUMBER
- ⊙ 2" WATER TABLE PIEZOMETER

FIGURE 27

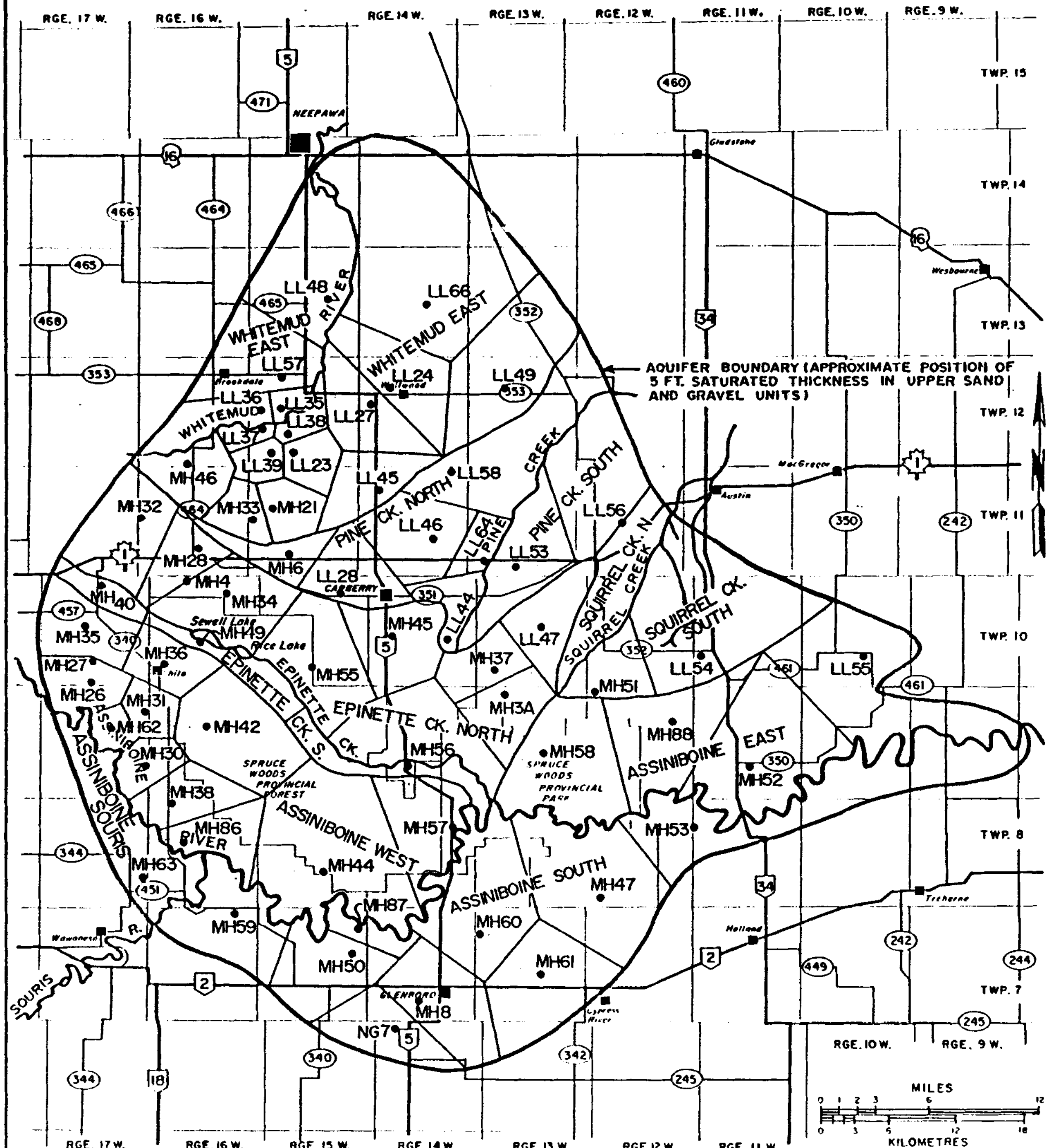
"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 – AQUIFER CAPACITY INVESTIGATIONS

ASSINIBOINE DELTA AQUIFER

GROUNDWATER MONITORING STATIONS

Manitoba Natural Resources
Water Resources

DRAWN	CHECKED	PREPARED	SUBMITTED	APPROVED	SCALE	DATE	SHEET	FILE NO.
R.R. Palka		F. Render	C. Gray	[signature]	AS SHOWN	86 06 27	27 OF 88	90-1-7-1141



LEGEND

•(5)MH (MN)51 GROUNDWATER MONITORING STATION

WEIGHTED POLYGONAL AREA

AQUIFER BASIN BOUNDARIES

FIGURE 28

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

ASSINIBOINE DELTA AQUIFER

BASIN BOUNDARIES AND THEISEN POLYGON NETWORK

DRAWN	R.R. Palka
CHECKED	
PREPARED	F.W. Render

Manitoba Natural Resources
Water Resources

SUBMITTED	APPROVED	SCALE	DATE	SHEET	FILE NO.
[signature]	[signature]	AS SHOWN	86 06 27	28 OF 88	90-1-7-1141

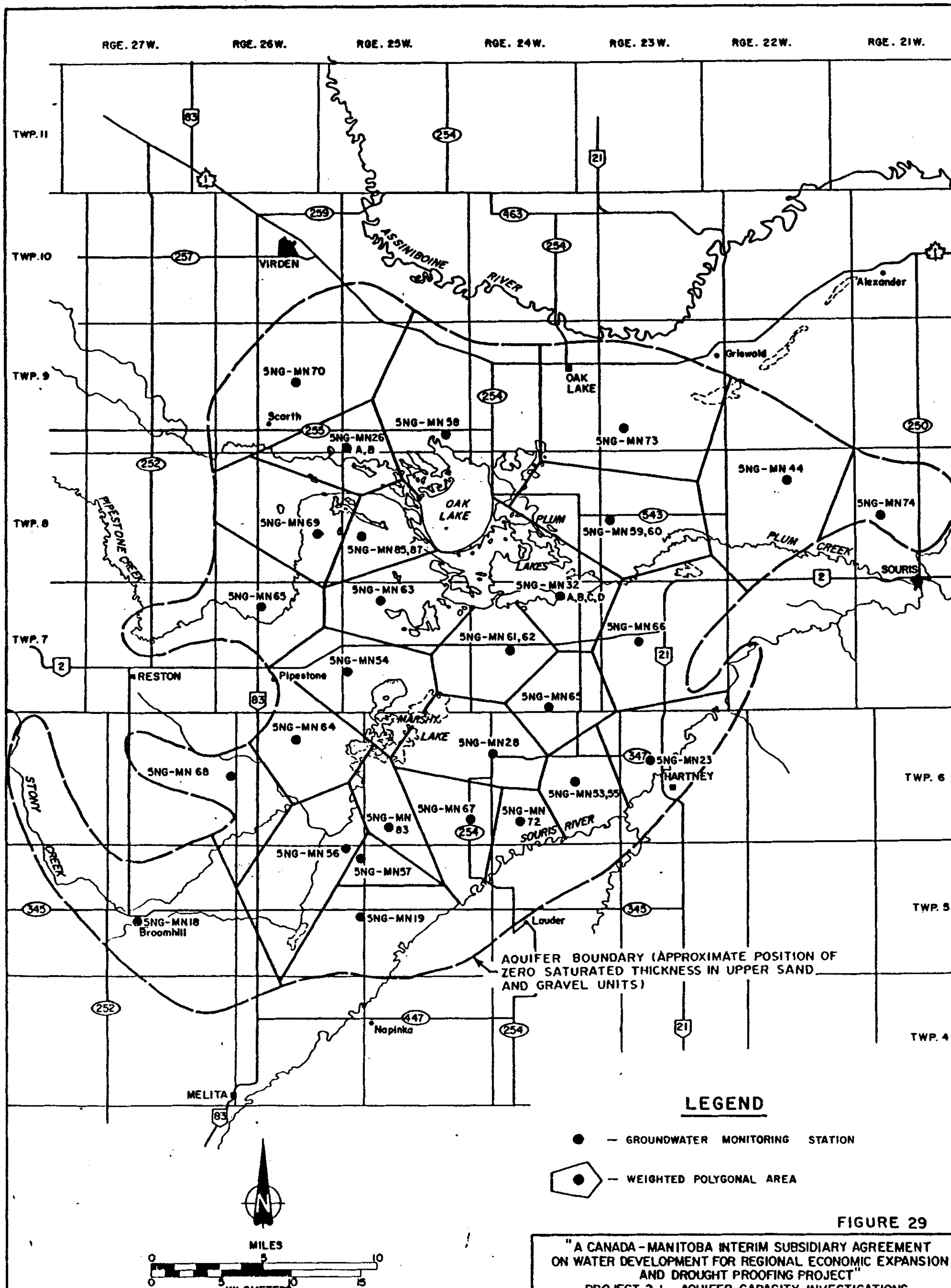


FIGURE 29

"A CANADA - MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

DRAWN F.B.R.	PROVINCE OF MANITOBA DEPARTMENT OF NATURAL RESOURCES WATER RESOURCES BRANCH	OAK LAKE AQUIFER
CHECKED		**THEISEN POLYGON NETWORK**
PREPARED W.H./F.W.R.	SUBMITTED / APPROVED	SCALE AS SHOWN · DATE 86 06 27 · SHEET 29 OF 88 · FILE No. 90-1-7-1141

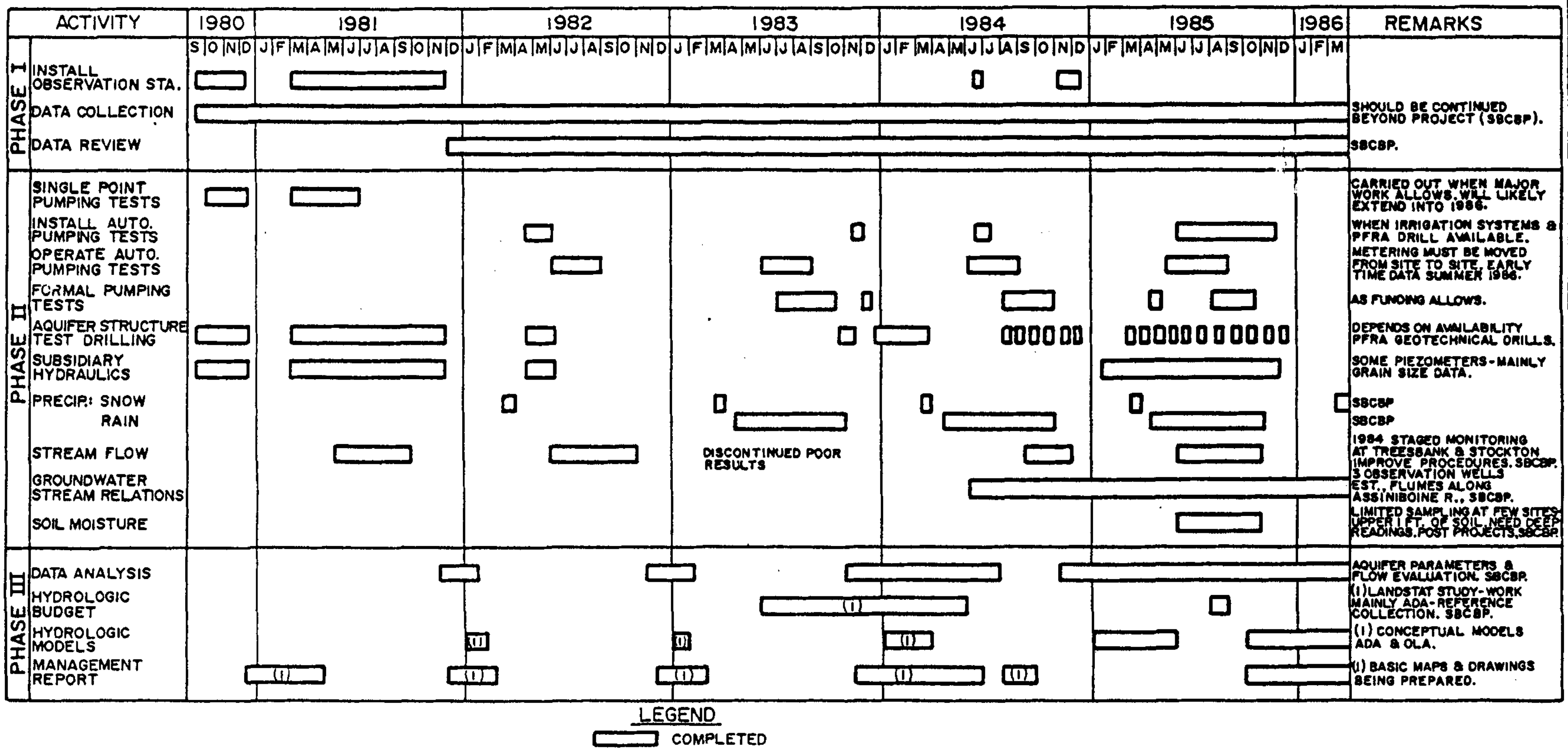


FIGURE 30

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

AQUIFER CAPACITY INVESTIGATION SCHEDULE

Manitoba Natural Resources
Water Resources

DRAWN	R.R. Polka
CHECKED	
PREPARED	F.W. Render
SUBMITTED	[signature]
APPROVED	[signature]
SCALE	AS SHOWN
DATE	86 06 27
SHEET	30 of 88
FILE NO.	90-1-7-1141

OLA-59A, 5" OBSERVATION WELL

LOG OLA-59A DRILLERS LOG

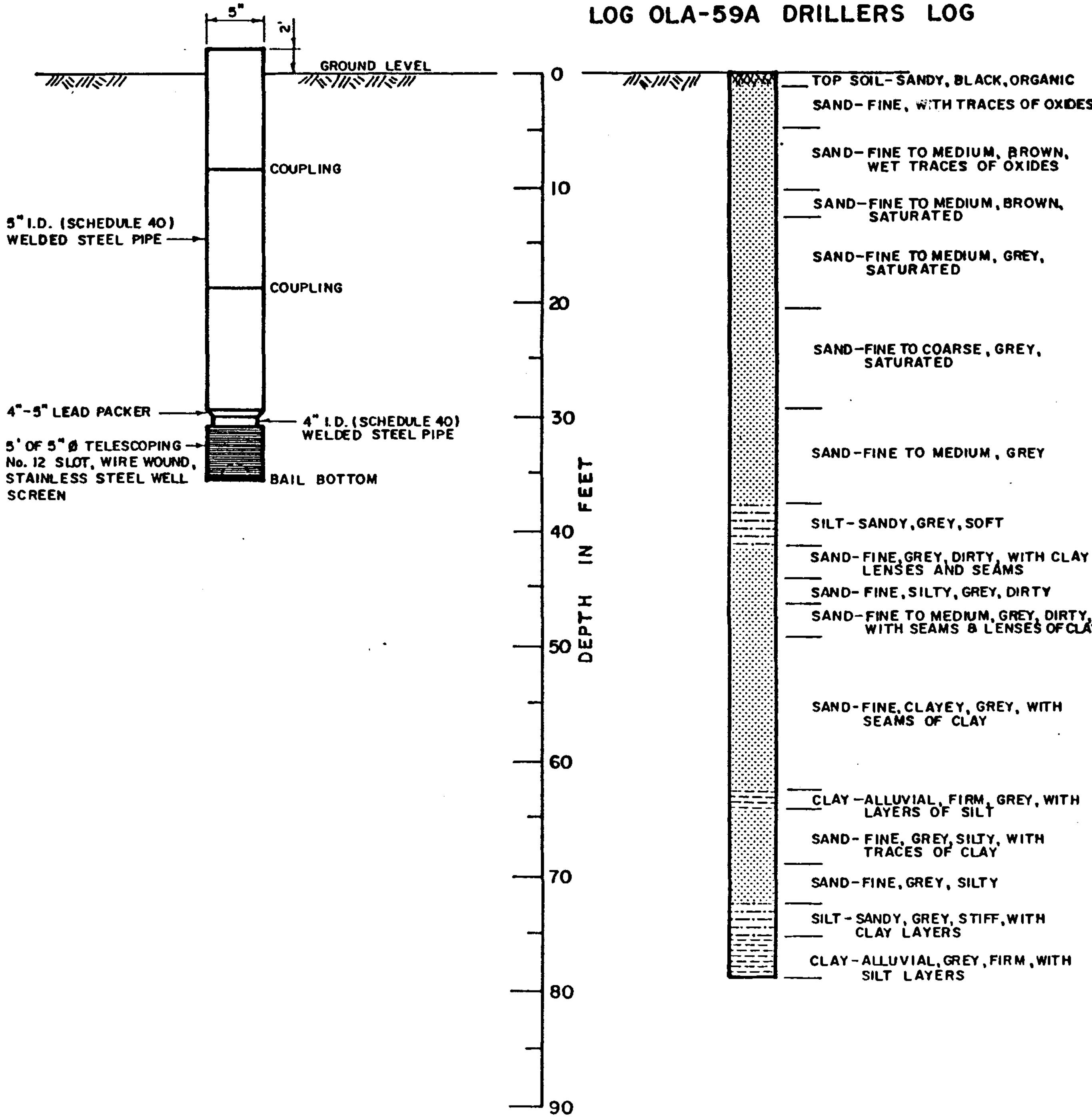


FIGURE 31

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

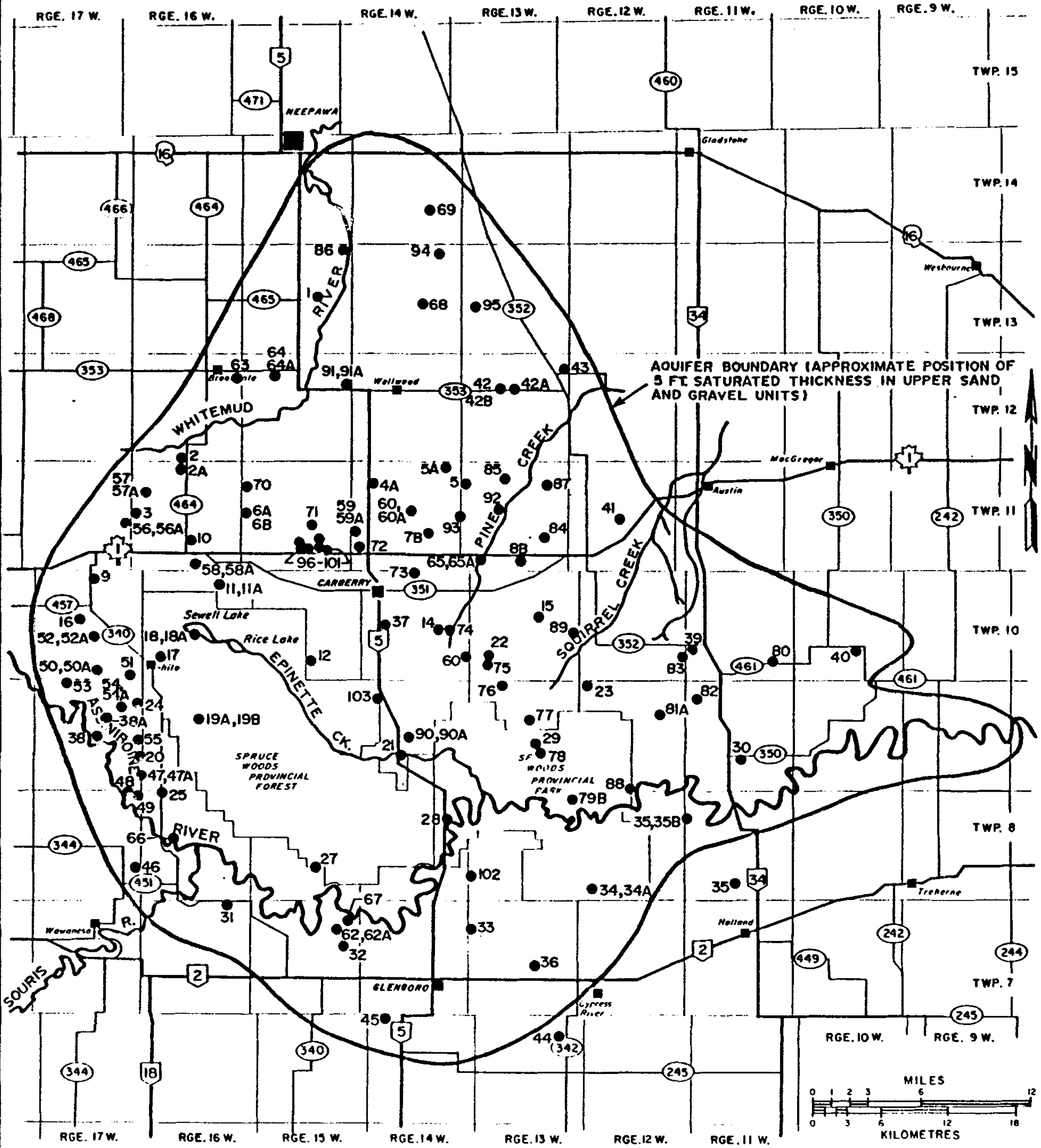
OAK LAKE AQUIFER

TYPICAL GROUNDWATER MONITORING STATION

Manitoba Natural Resources

Water Resources

DRAWN	F.B.R.
CHECKED	
PREPARED	W.H.
SUBMITTED	[signature]
APPROVED	[signature]
SCALE	AS SHOWN
DATE	86 06 27
SHEET	31 of 88
FILE NO.	90-1-7-1141



LEGEND

●45 1980 TO 1985 TEST HOLE WITH FIELD NUMBER

FIGURE 32

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

ASSINIBOINE DELTA AQUIFER

PROJECT TEST HOLES

DRAWN	R.R. Palka
CHECKED	
PREPARED	F. W. Render

Manitoba Natural Resources
Water Resources

SUBMITTED	APPROVED	SCALE	DATE	SHEET	FILE NO.
		AS SHOWN	86 06 27	32 OF 88	90-1-7-1141

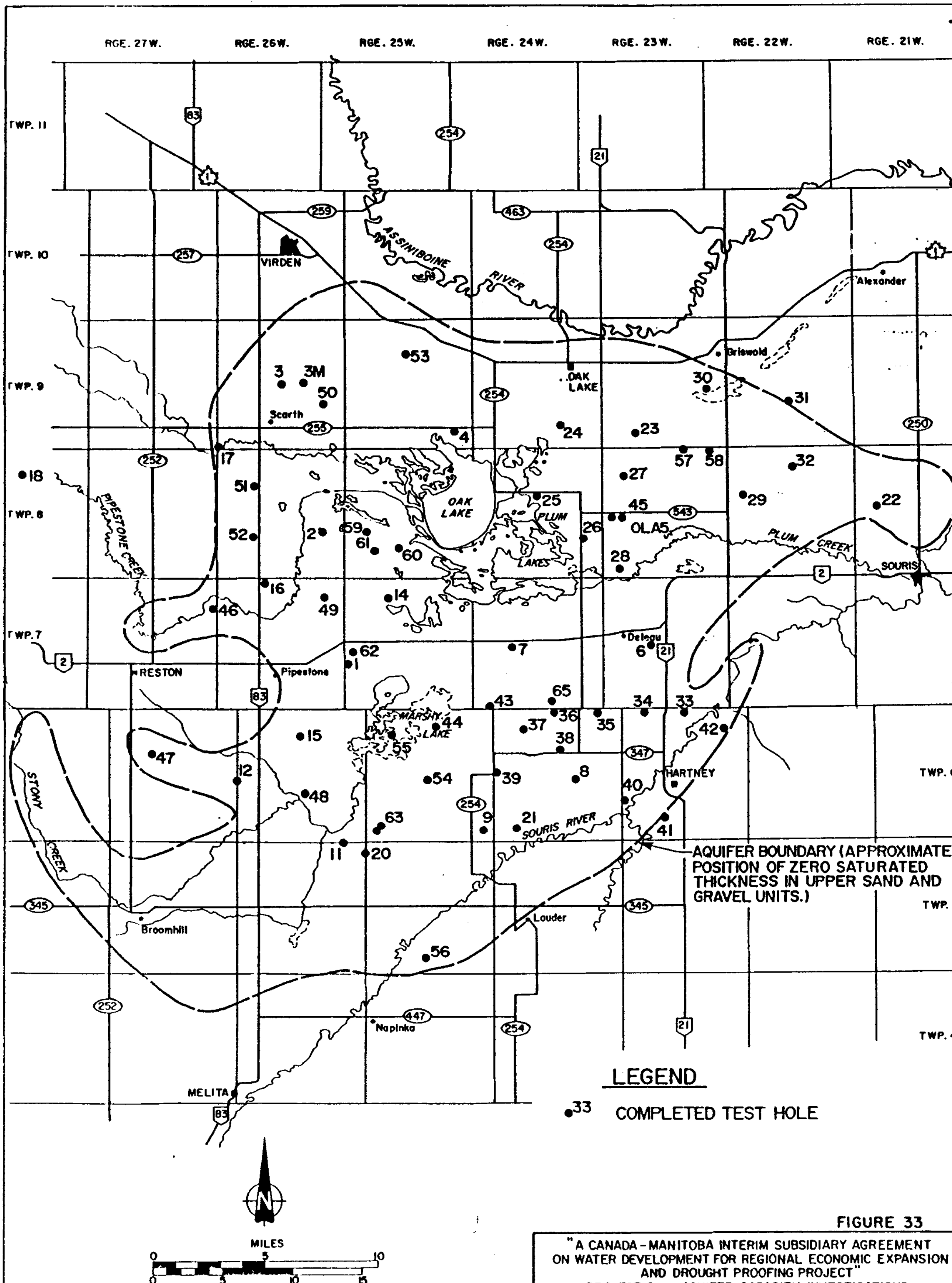
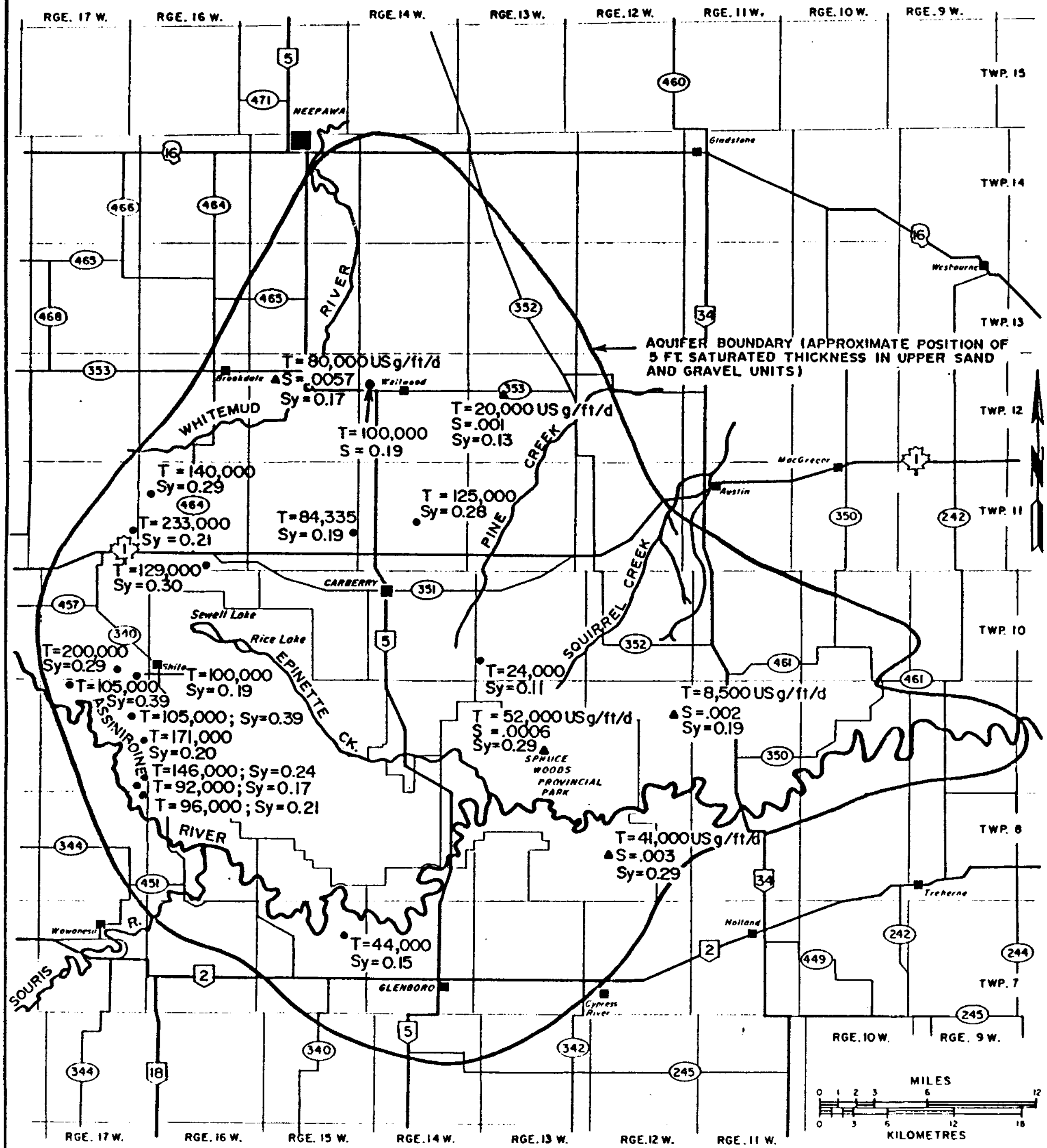


FIGURE 33

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

DRAWN R.R. Palka	PROVINCE OF MANITOBA DEPARTMENT OF NATURAL RESOURCES WATER RESOURCES BRANCH	OAK LAKE AQUIFER PFRA DRILL HOLES 1980-85
CHECKED	SUBMITTED	APPROVED
PREPARED F.W. Render	SCALE AS SHOWN	DATE 86 06 27
SHEET 33 OF 88	FILE No 90-1-7-1141	



LEGEND

- ● AUTOMATIC PUMPING TEST SITE
- ▲ FORMAL PUMPING TEST SITE

FIGURE 34

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

ASSINIBOINE DELTA AQUIFER

PROJECT PUMPING TESTS

Manitoba Natural Resources
Water Resources

DRAWN	R.R. Palka
CHECKED	
PREPARED	F.W. Render
SUBMITTED	[signature]
APPROVED	[signature]
SCALE	AS SHOWN
DATE	860627
SHEET	34 OF 88
FILE NO.	90-1-7-1141

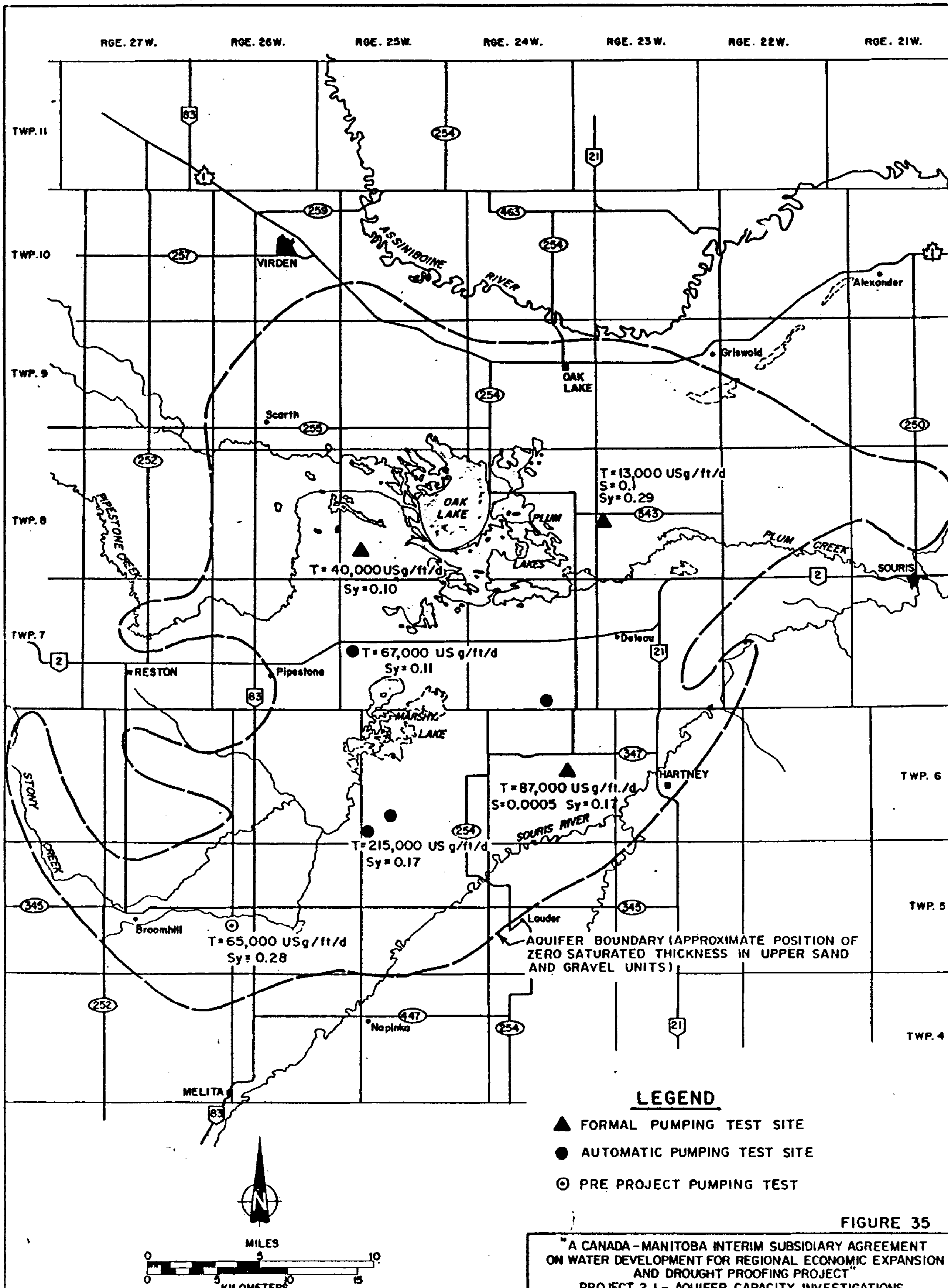
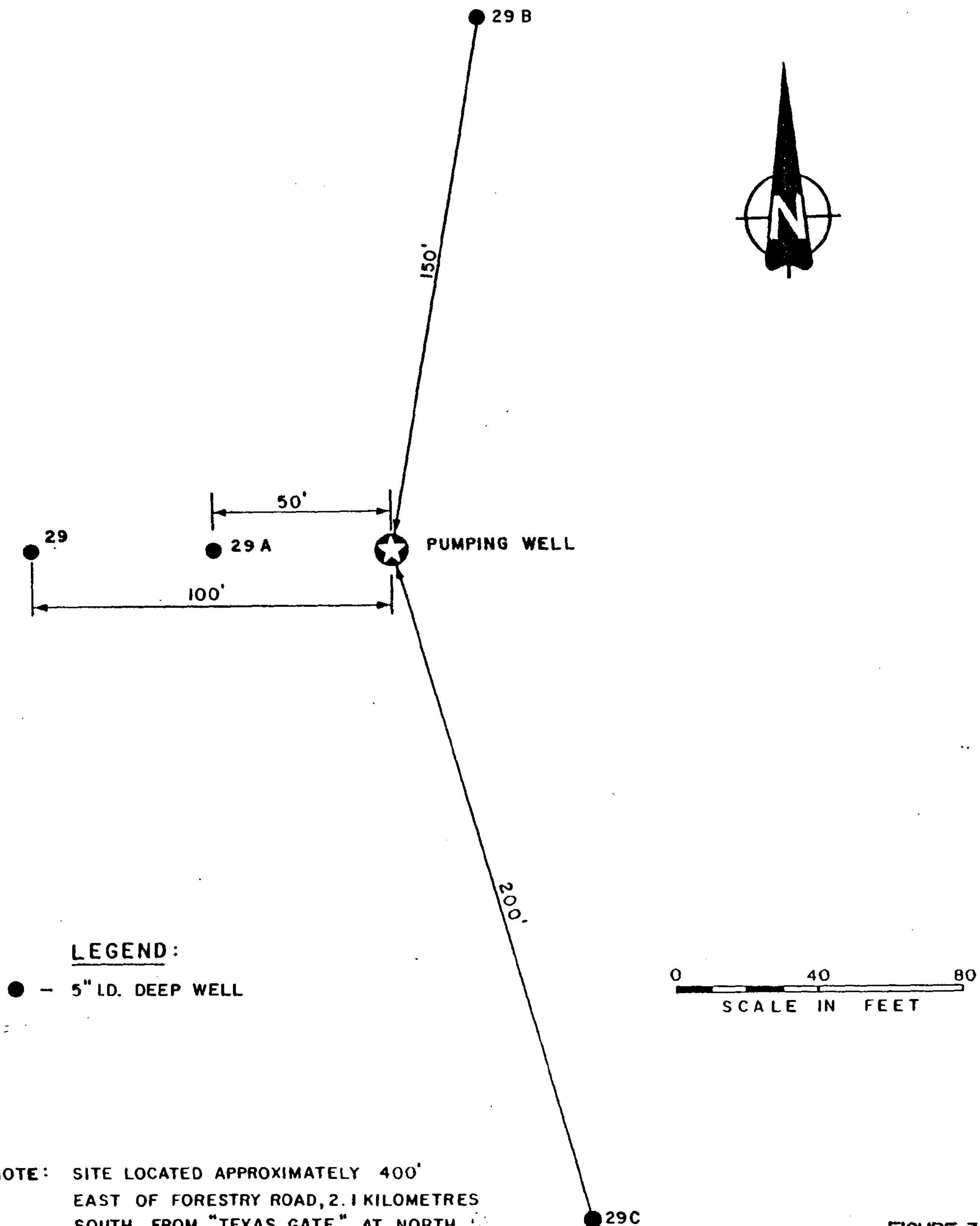


FIGURE 35

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

DRAWN	PROVINCE OF MANITOBA		OAK LAKE AQUIFER
F.B.R.	DEPARTMENT OF NATURAL RESOURCES		
CHECKED	WATER RESOURCES BRANCH		**PROJECT PUMPING TESTS**
PREPARED	SUBMITTED	APPROVED	
F.W. Render	[signature]	[signature]	SCALE: AS SHOWN · DATE: 86 06 27 · SHEET: 35 OF 88 · FILE No.: 90-1-7-1141



NOTE: SITE LOCATED APPROXIMATELY 400' EAST OF FORESTRY ROAD, 2.1 KILOMETRES SOUTH FROM "TEXAS GATE" AT NORTH BOUNDARY OF SPRUCE WOODS PROV. PARK LOCATION NEAR CENTER OF SECTION 15 – TWP. 9 – RGE. 13 W.

FIGURE 36

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

PROVINCE OF MANITOBA

DEPARTMENT OF NATURAL RESOURCES

WATER RESOURCES BRANCH

SITE PLAN FOR ADA 29 PUMPING TEST

PREPARED	DRAWN	SUBMITTED	APPROVED	SCALE	DATE	SHEET	FILE NO
F. W. Render	F.B.R. / CHECKED	[signature]	[signature]	AS SHOWN	86 06 27	36 of 88	90-1-7-1141

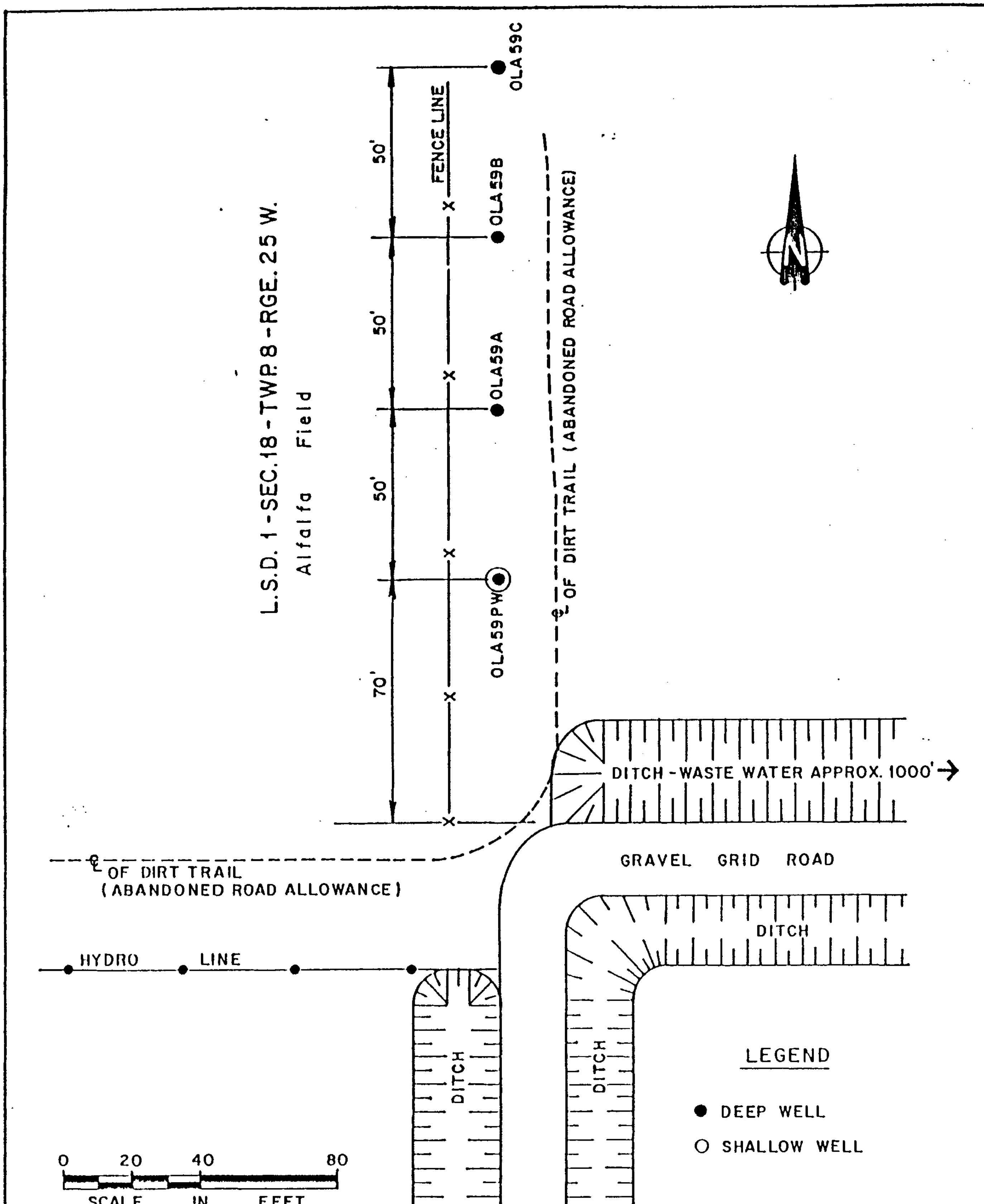


FIGURE 37

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

PROVINCE OF MANITOBA

DEPARTMENT OF NATURAL RESOURCES

WATER RESOURCES BRANCH

SITE PLAN FOR OLA-59 PUMPING TEST

PREPARED	DRAWN	SUBMITTED	APPROVED	SCALE	DATE	SHEET	
F. Render	F.B.R.			AS SHOWN	86 06 27	37 OF 88	90-1-7-1141
	CHECKED						

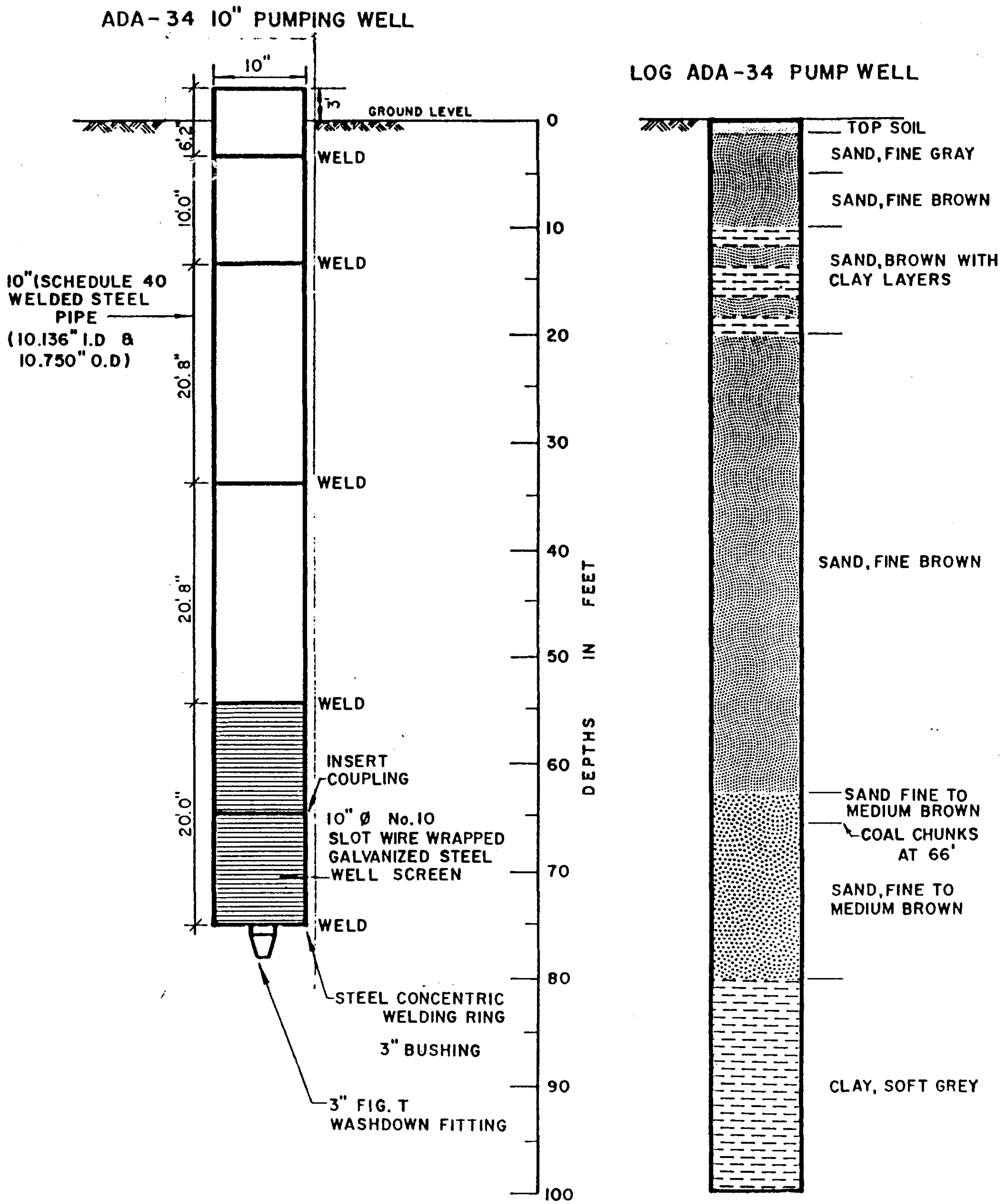


FIGURE 38

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

PROVINCE OF MANITOBA

DEPARTMENT OF NATURAL RESOURCES

WATER RESOURCES DIVISION

ASSINIBOINE DELTA AQUIFER

ADA-34 TYPICAL PUMP WELL

PREPARED	DRAWN	SUBMITTED	APPROVED	SCALE	DATE	SHEET	FILE NO.
W. H	F.R. CHECKED			AS SHOWN	86 06 27	38 OF 88	90-1-7-1141

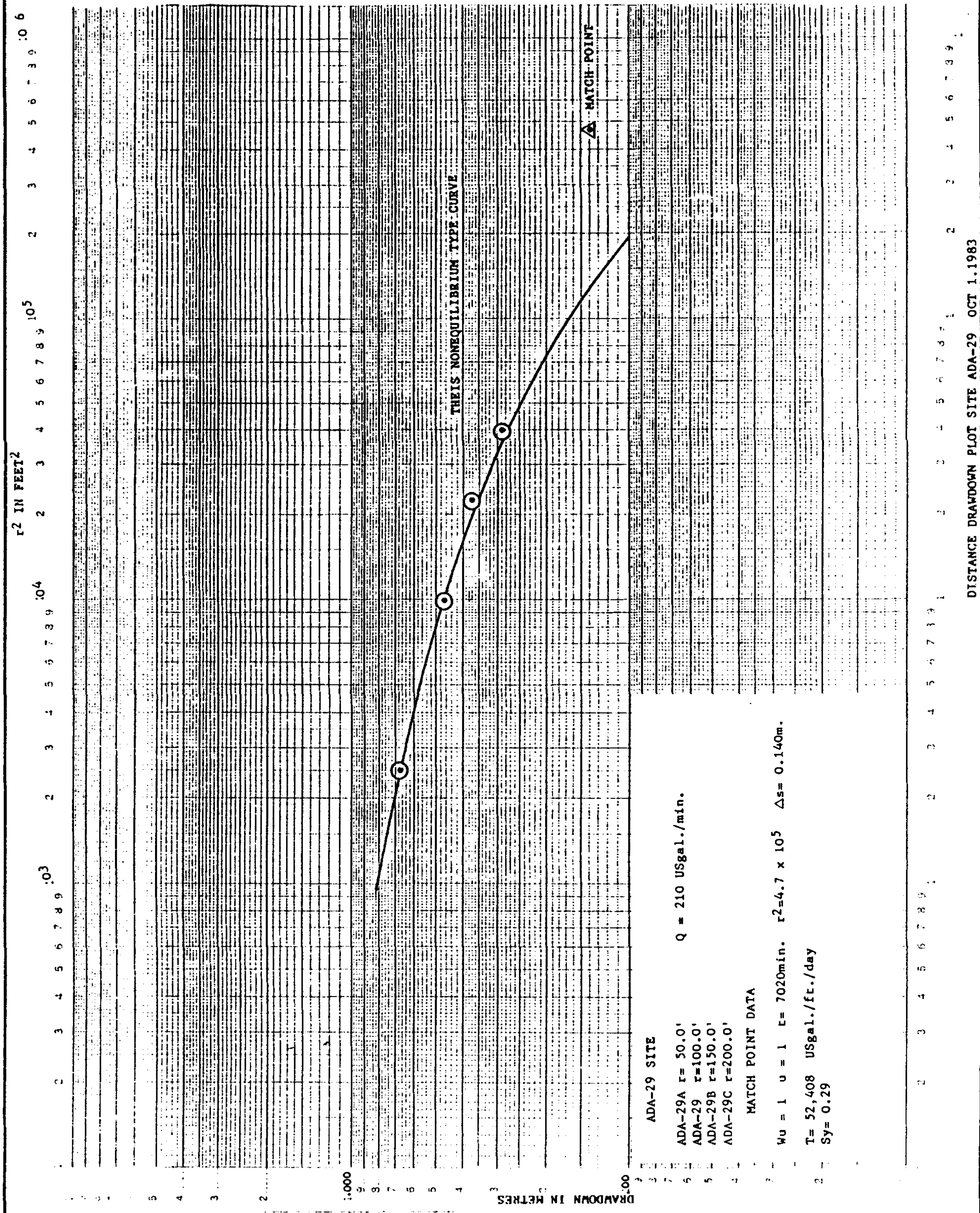


FIGURE 39

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

DRAWN F.B.R.	Manitoba Natural Resources Water Resources	ASSINIBOINE DELTA AQUIFER
CHECKED		DISTANCE DRAWDOWN AT SITE ADA-29
PREPARED W.H. / F.W.R.	SUBMITTED / APPROVED	SCALE AS SHOWN · DATE 86 06 27 · SHEET 39 OF 88 · FILE NO. 90-1-7-1141

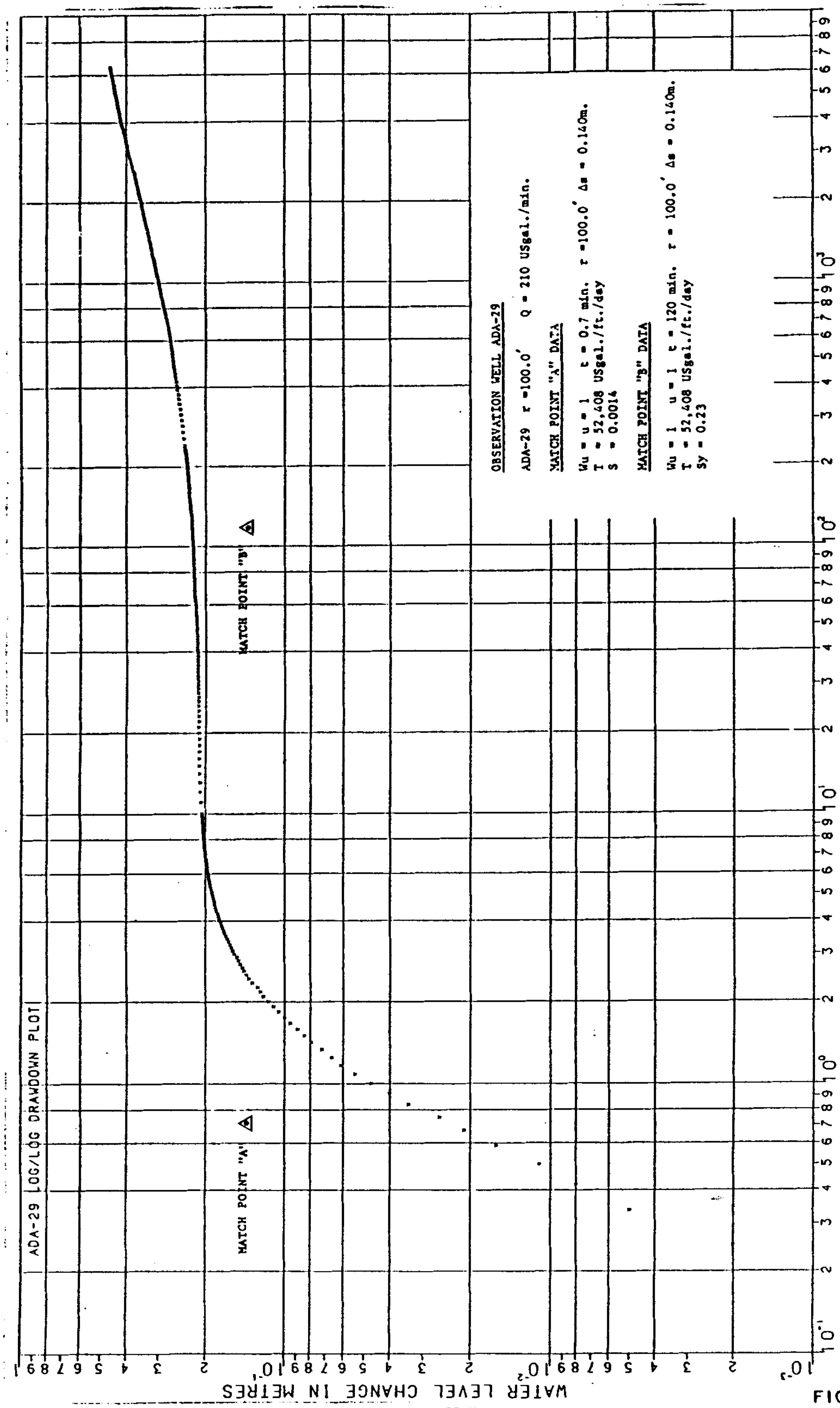
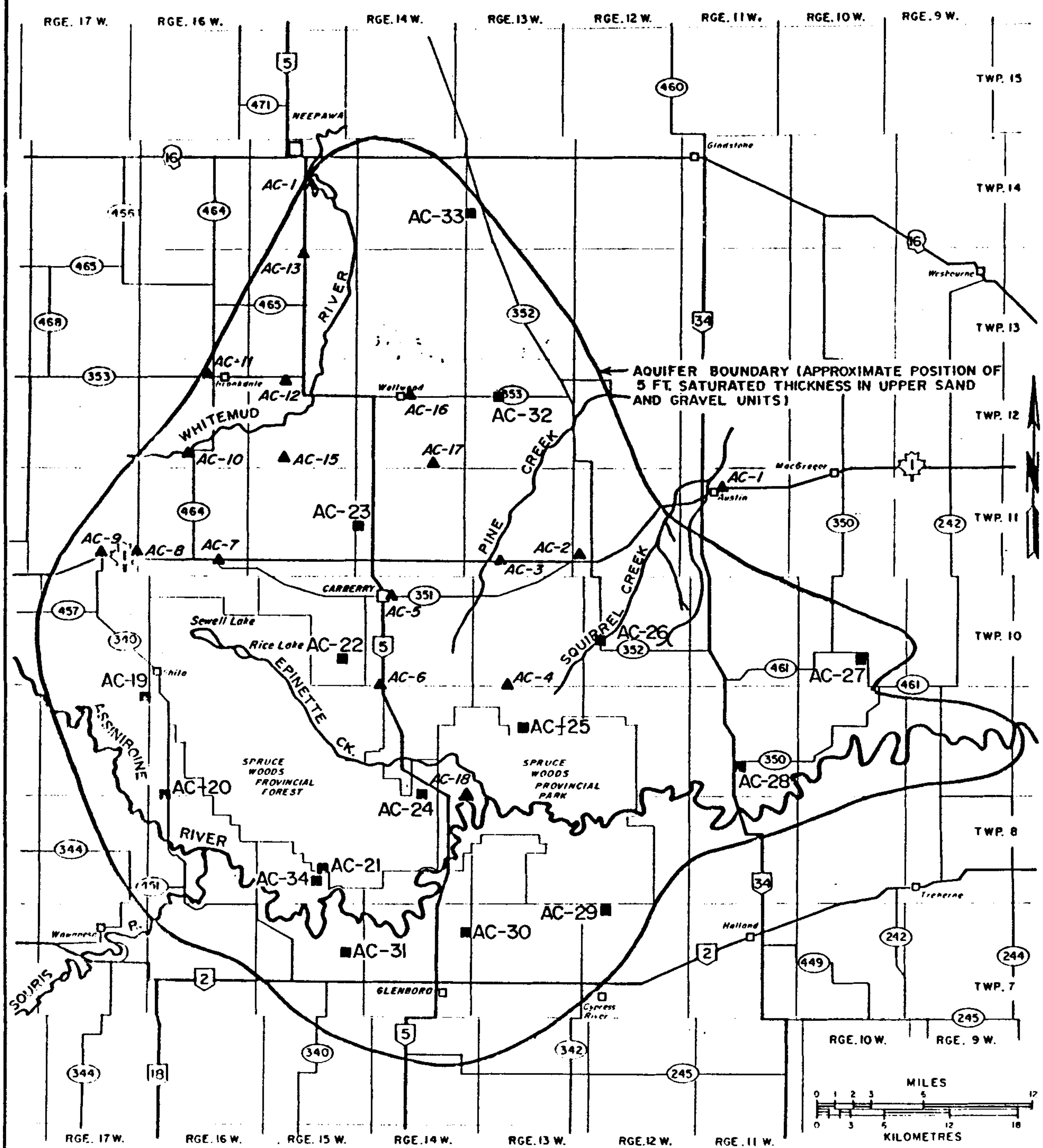


FIGURE 40

"A CANADA–MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 – AQUIFER CAPACITY INVESTIGATIONS

DRAWN F.B.R.	Manitoba Natural Resources Water Resources	ASSINIBOINE DELTA AQUIFER
CHECKED		**TIME DRAWDOWN AT SITE ADA-29**
PREPARED W.H./F.W.R.	SUBMITTED / APPROVED	SCALE AS SHOWN / DATE 86 06 27 / SHEET 40 OF 88 / FILE NO. 90-1-7-1141



LEGEND

■ PROJECT SNOW SURVEY STATION

▲ ESTABLISHED SNOW SURVEY STATION (circa 1965)

FIGURE 41

"A CANADA–MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 – AQUIFER CAPACITY INVESTIGATIONS

ASSINIBOINE DELTA AQUIFER

SNOW SURVEY STATIONS

Manitoba Natural Resources
Water Resources

DRAWN F.B.R.
CHECKED
PREPARED W.H.
SUBMITTED
APPROVED
SCALE AS SHOWN
DATE 86 06 27
SHEET 41 OF 88
FILE NO. 90-1-7-1141

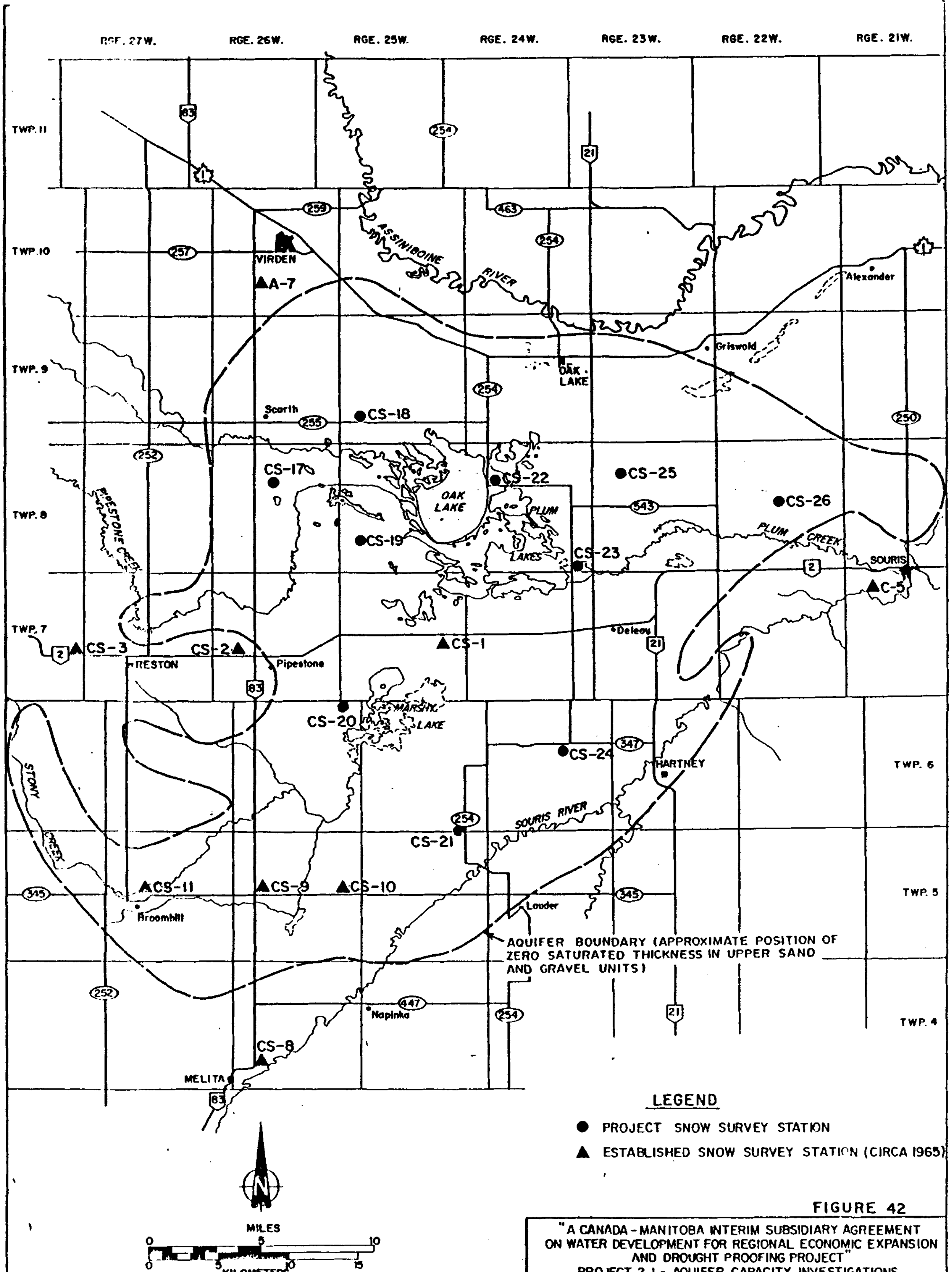


FIGURE 42

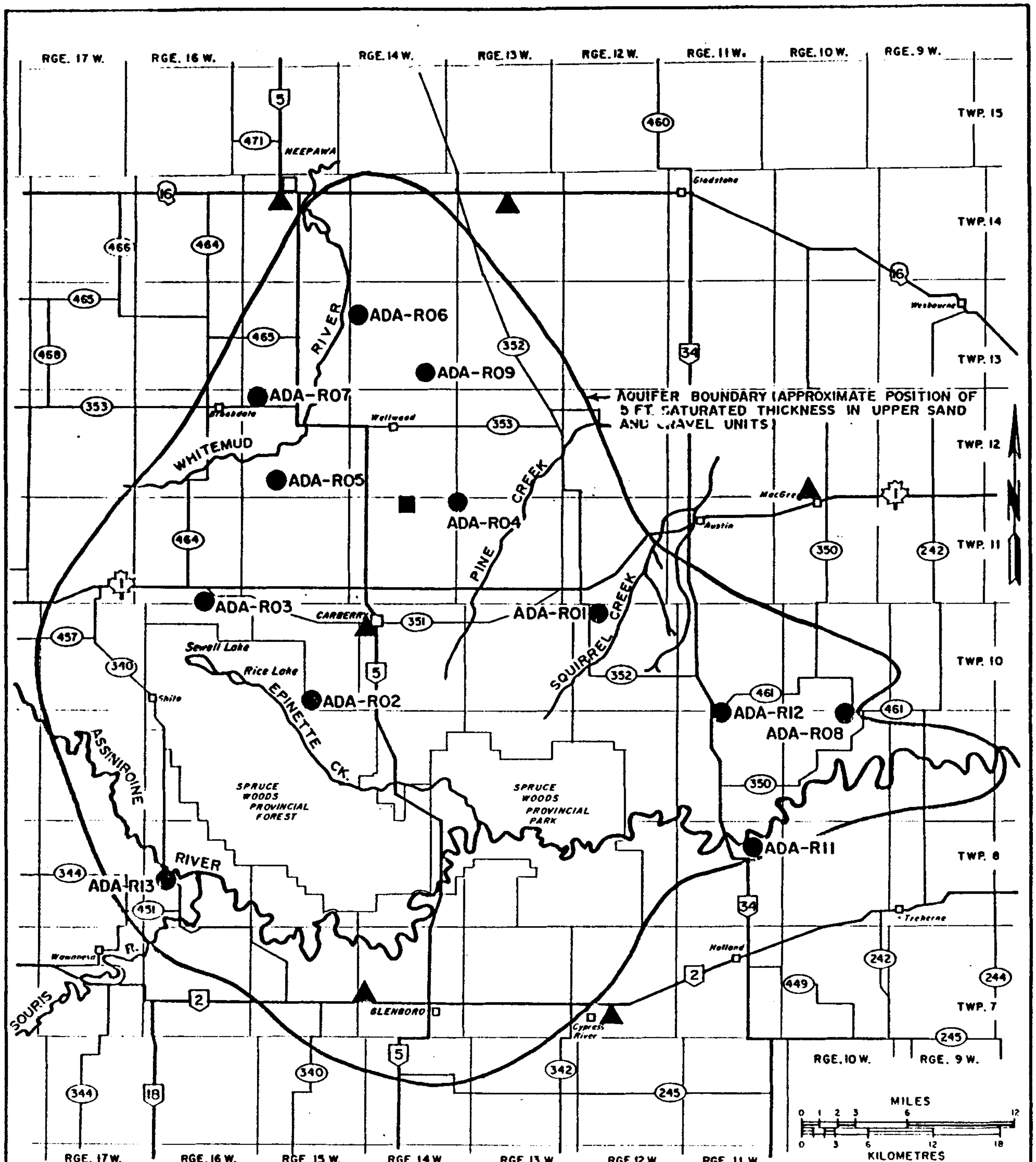
"A CANADA - MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

OAK LAKE AQUIFER

SNOW SURVEY STATIONS

DRAWN F.B.R.	PROVINCE OF MANITOBA DEPARTMENT OF NATURAL RESOURCES WATER RESOURCES BRANCH	
CHECKED		
PREPARED W.H.	SUBMITTED	APPROVED

SCALE	DATE	SHEET	FILE No.
AS SHOWN	86 06 27	42 OF 88	90-1-7-1141



LEGEND

● — W.R.B. DAILY RAIN GAUGE STATION

■ — W.R.B. AUTOMATIC DAILY RAIN GAUGE STATION

▲ — A.E.S. DAILY RAIN GAUGE STATION

FIGURE 43

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

ASSINIBOINE DELTA AQUIFER

RAIN GAUGE STATIONS

Manitoba Natural Resources
Water Resources

DRAWN	CHECKED	PREPARED	SUBMITTED	APPROVED	SCALE	DATE	SHEET	FILE NO.
F.B.R.		W.H.	[signature]	[signature]	AS SHOWN	86 06 27	43 OF 66	90-1-7-1141

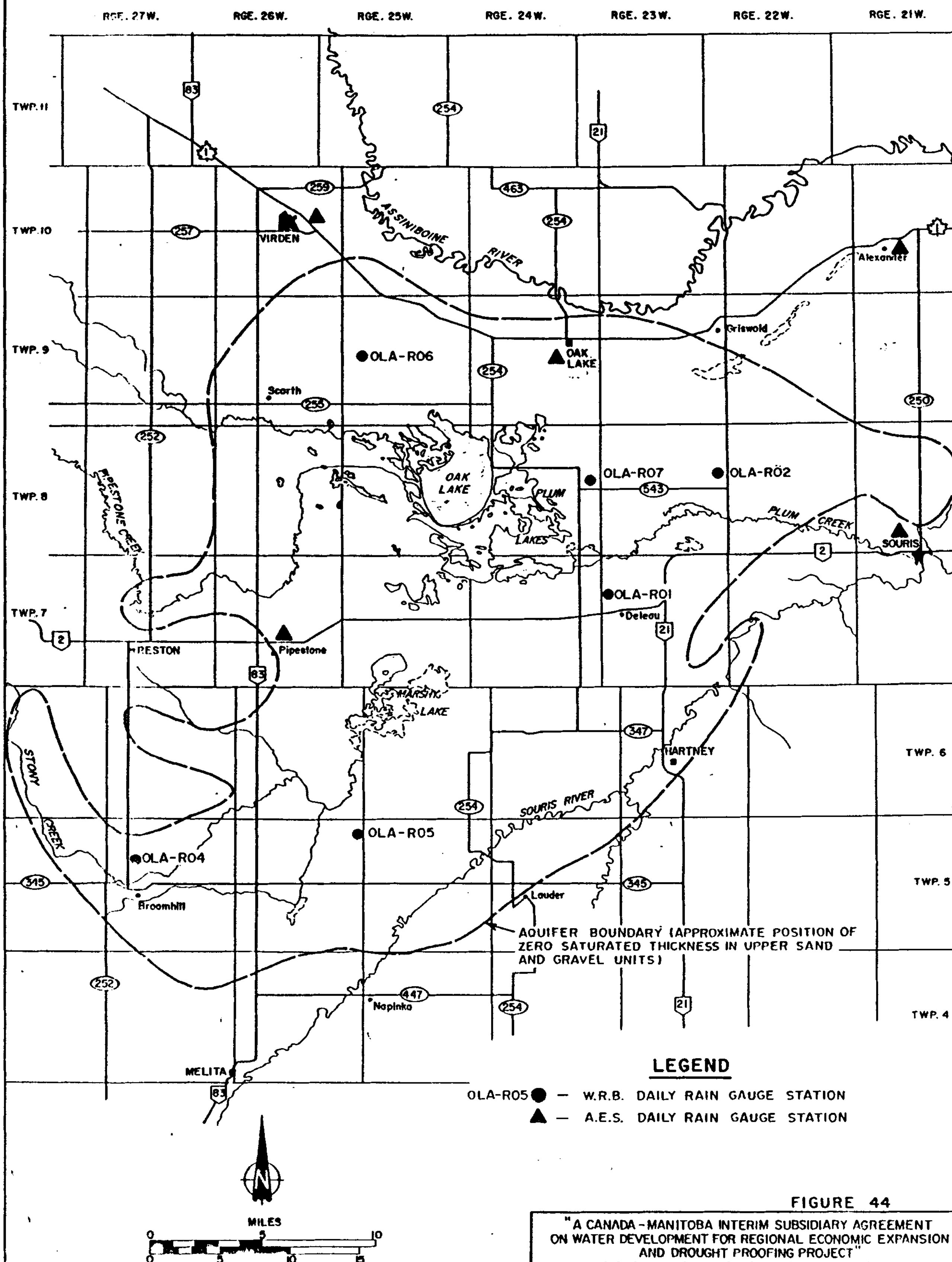


FIGURE 44

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

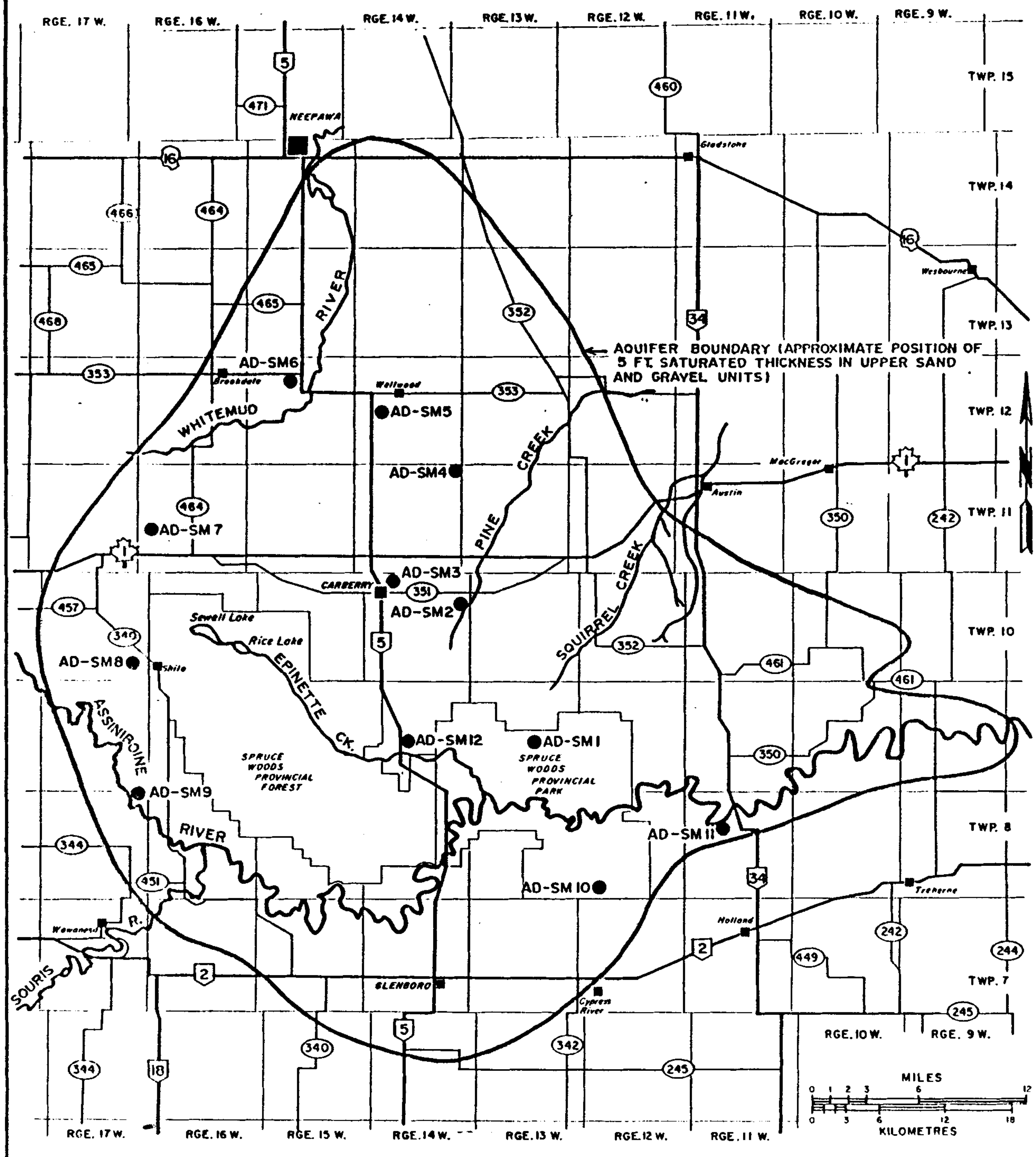
OAK LAKE AQUIFER

RAIN GAUGE STATIONS

PROVINCE OF MANITOBA
DEPARTMENT OF NATURAL RESOURCES
WATER RESOURCES BRANCH

DRAWN	CHECKED	PREPARED	SUBMITTED	APPROVED
F.B.R.		F.W. Render	[signature]	[signature]

SCALE	DATE	SHEET	FILE No.
AS SHOWN	86 06 27	44 OF 88	90-1-7-1141



AD-SM 12● — SURFICIAL SOIL MOISTURE SITES

FIGURE 45

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

Manitoba Natural Resources
Water Resources

ASSINIBOINE DELTA AQUIFER

SURFICIAL SOIL MOISTURE STATIONS

DRAWN	CHECKED	PREPARED	SUBMITTED	APPROVED	SCALE	DATE	SHEET	FILE NO.
F.B.R.		F.W. Render	[signature]	[signature]	AS SHOWN	86 06 27	45 OF 88	90-1-7-1141

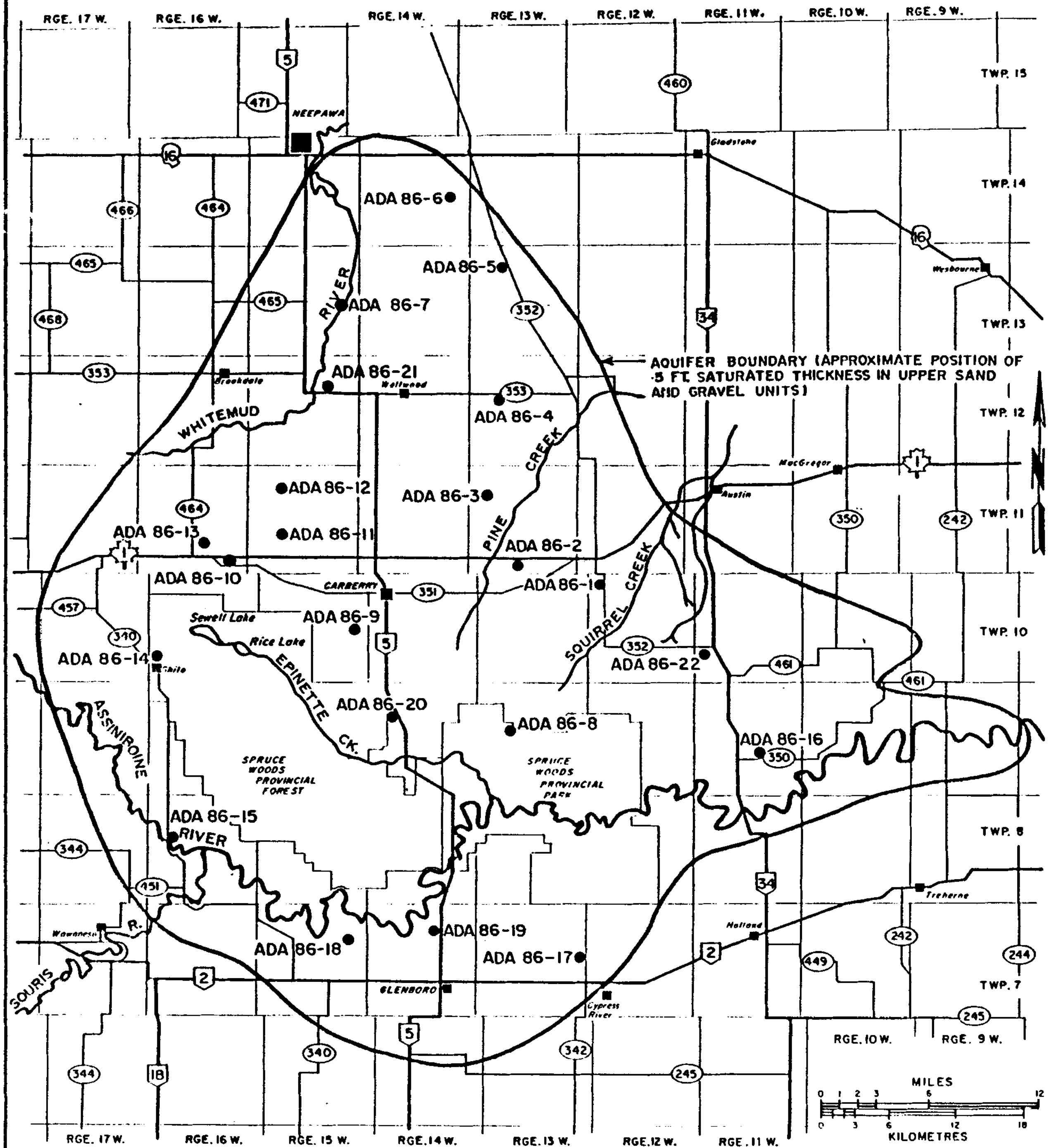


FIGURE 46

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 – AQUIFER CAPACITY INVESTIGATIONS

Manitoba Natural Resources
Water Resources

ASSINIBOINE DELTA AQUIFER

WOODED AREA SNOW SURVEY 1986

DRAWN F.B.R.	CHECKED	PREPARED F. W. Render	SUBMITTED / APPROVED
SCALE AS SHOWN	DATE 86 06 27	SHEET 46 OF 88	FILE NO. 90-1-7-1141

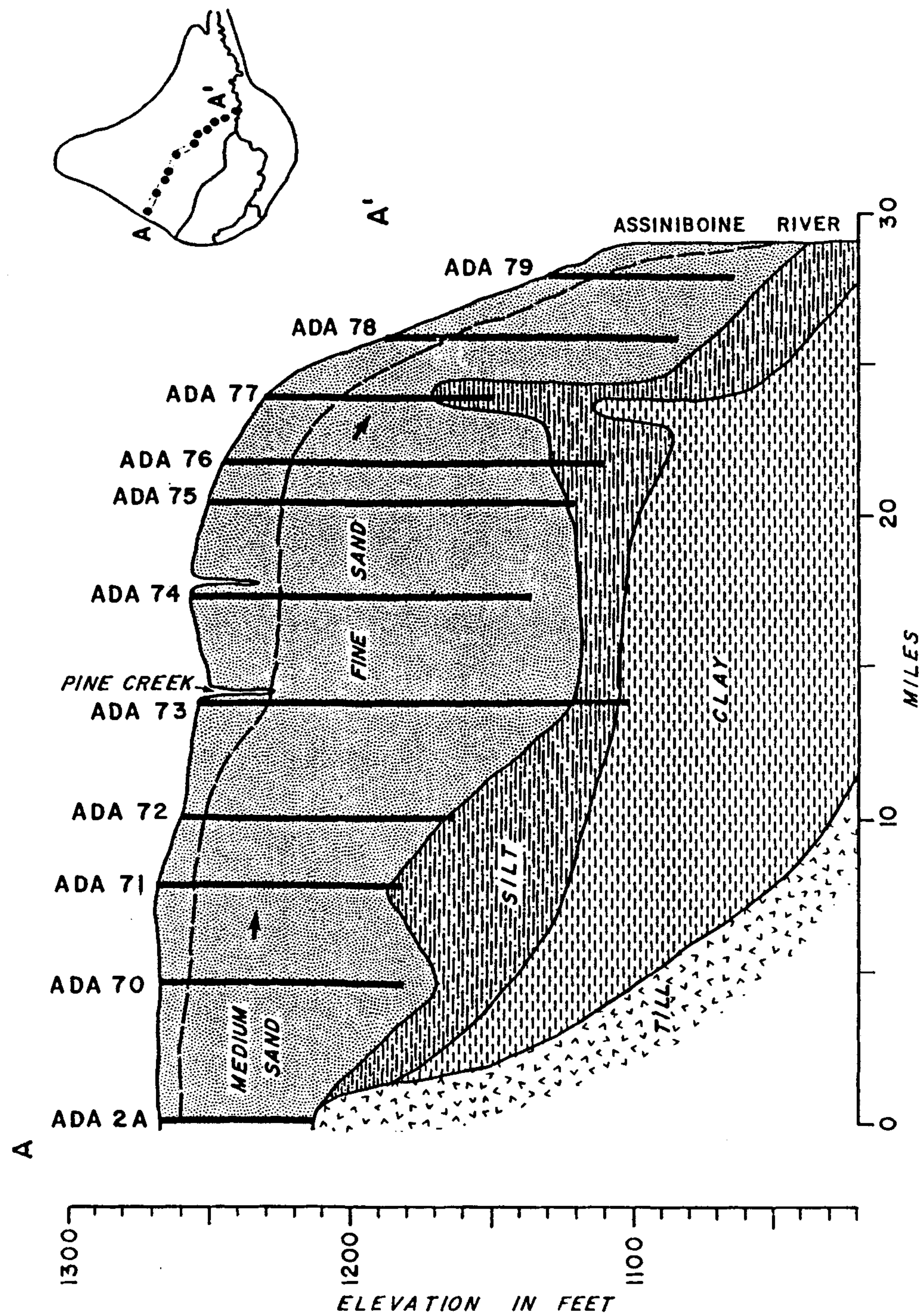


FIGURE 47

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

DRAWN M. Manolatos	Manitoba Natural Resources Water Resources	ASSINIBOINE DELTA AQUIFER
CHECKED		HYDRAULIC PROFILE
PREPARED F. W. Render	SUBMITTED / APPROVED	SCALE AS SHOWN; DATE 86 06 27; SHEET 47 OF 88; FILE NO. 90-1-7-1141

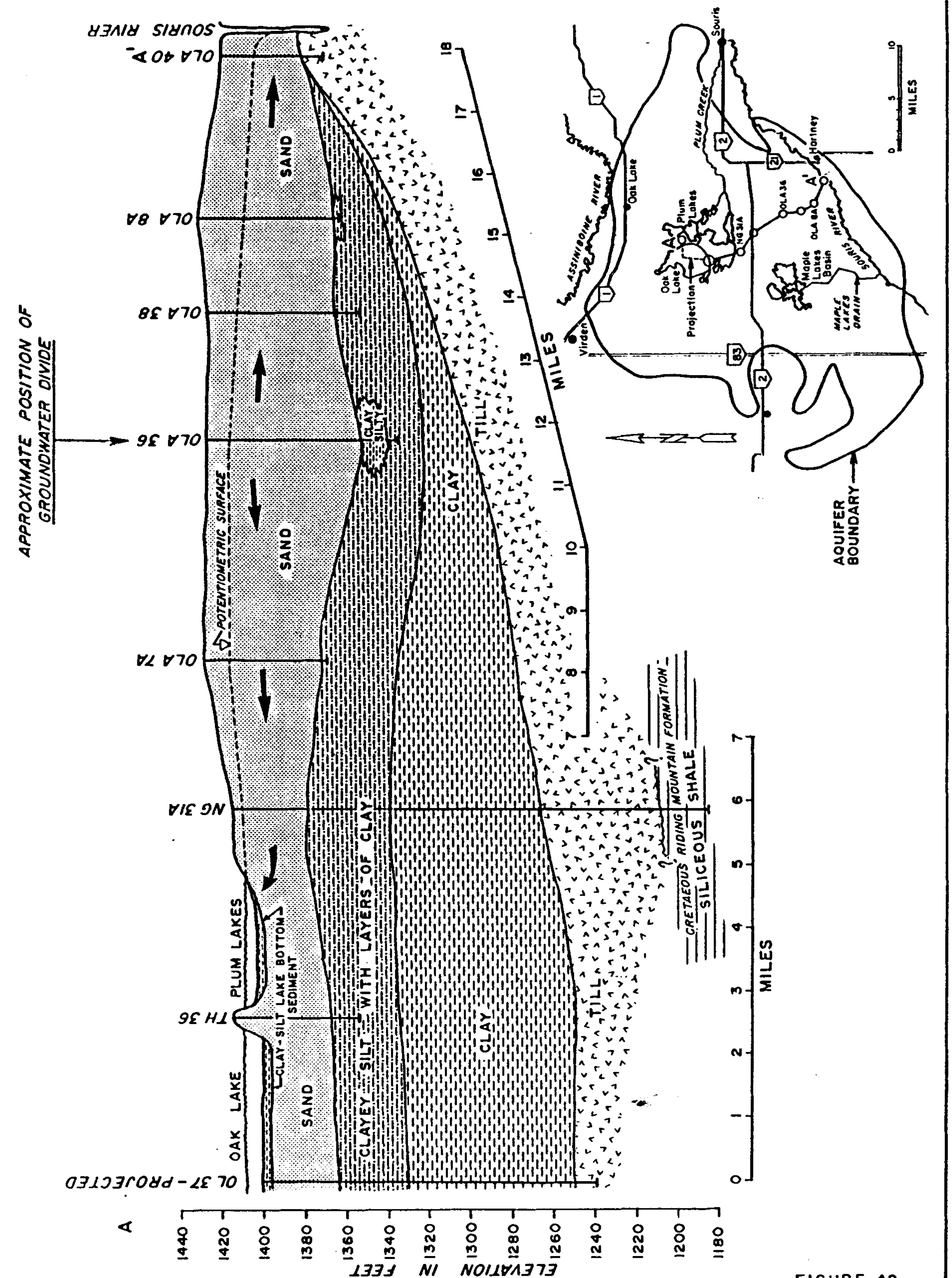


FIGURE 48

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

DRAWN	Manitoba Natural Resources Water Resources	OAK LAKE AQUIFER
F.B.R.		**HYDRAULIC PROFILE**
CHECKED		
PREPARED F.W. Render	SUBMITTED / APPROVED	SCALE AS SHOWN · DATE 86 06 27 · SHEET 48 OF 88 · FILE NO. 90-1-7-1141

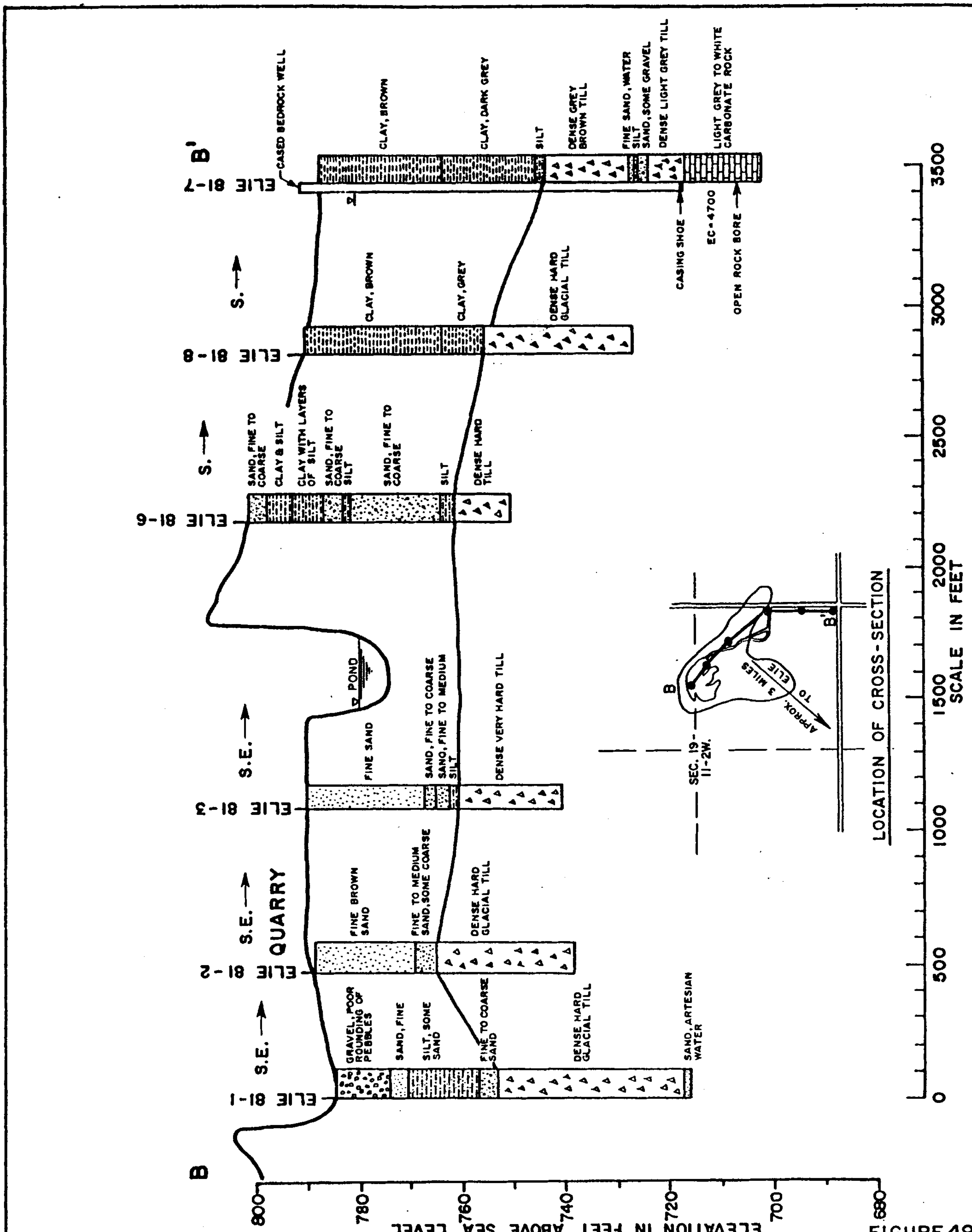


FIGURE 49

CAN-MAN INTERIM SUBSIDIARY AGREEMENT ON WATER
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

PROVINCE OF MANITOBA
DEPARTMENT OF NATURAL RESOURCES
WATER RESOURCES BRANCH

ELIE AQUIFER

SOUTHERLY HYDROGEOLOGIC CROSS-SECTION

PREPARED	DRAWN R.R.P.	SUBMITTED	APPROVED	SCALE AS SHOWN	DATE 86 06 27	SHEET 49 OF 88	FILE NO. 90-1-7-1141
F.W. RENDER	CHECKED						

MG 7961

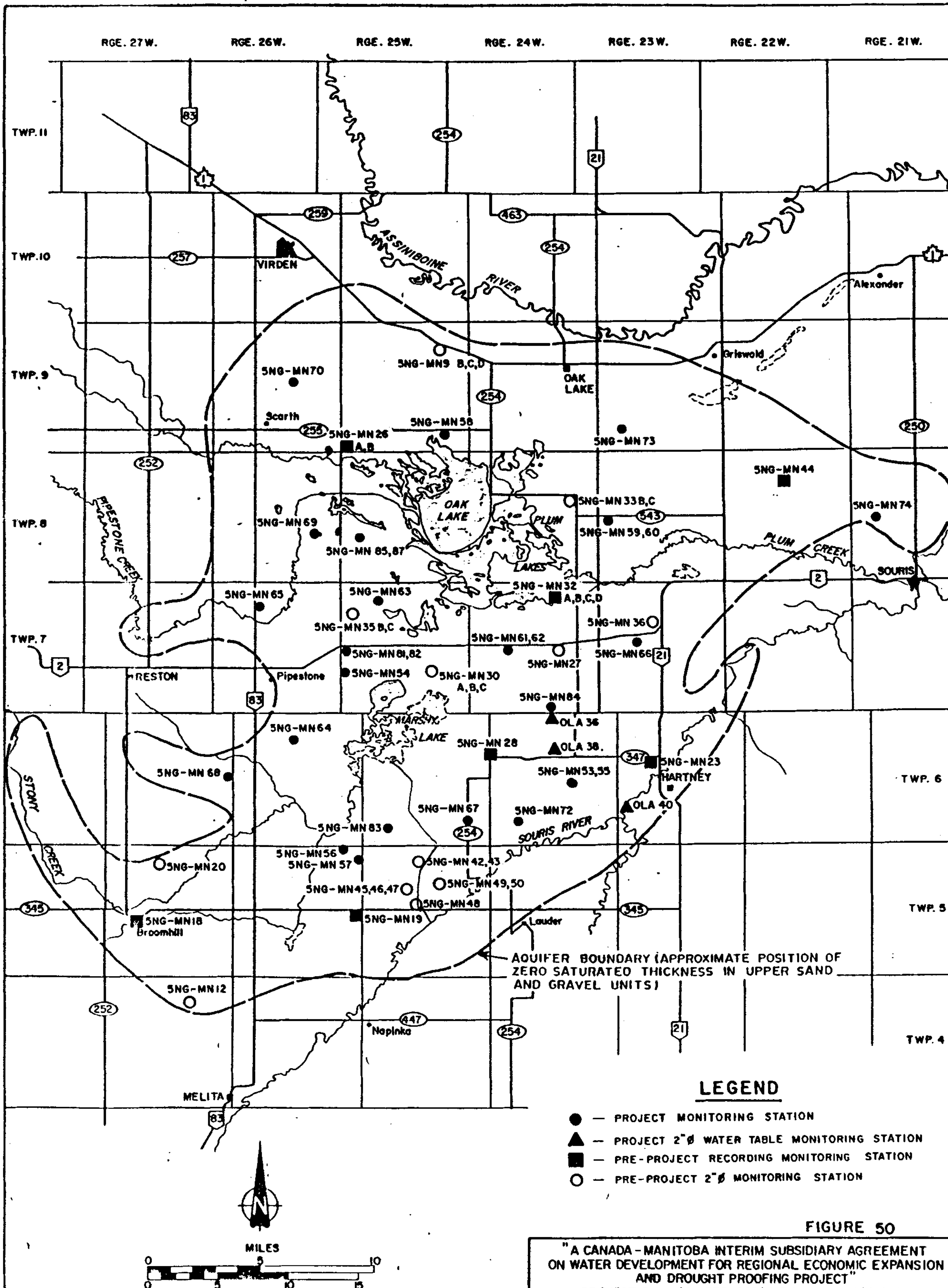


FIGURE 50

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

DRAWN F.B.R.	PROVINCE OF MANITOBA DEPARTMENT OF NATURAL RESOURCES WATER RESOURCES BRANCH	OAK LAKE AQUIFER **GROUNDWATER MONITORING STATIONS**
CHECKED		
PREPARED W.H./F.W.R.	SUBMITTED [signature] / APPROVED [signature]	SCALE AS SHOWN / DATE 86 06 27 / SHEET 50 OF 88 / FILE No 90-1-7-1141

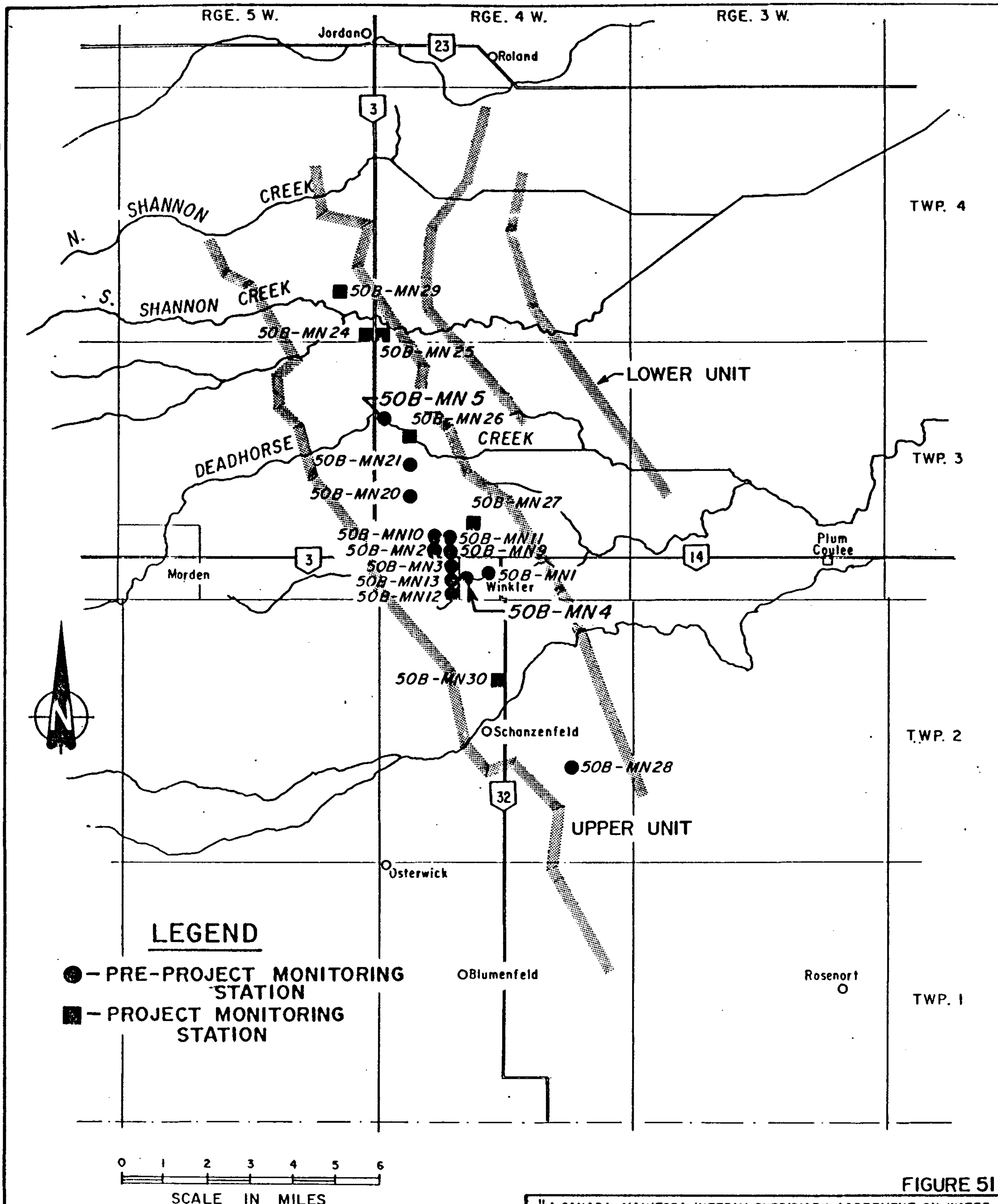


FIGURE 51

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

DRAWN F.B.R.	Manitoba Natural Resources	WINKLER AQUIFER
CHECKED	Water Resources	GROUNDWATER MONITORING STATIONS
PREPARED F.W. Render	SUBMITTED / APPROVED	SCALE AS SHOWN · DATE 86 06 27 · SHEET 51 OF 88 · FILE NO. 90-1-7-1141

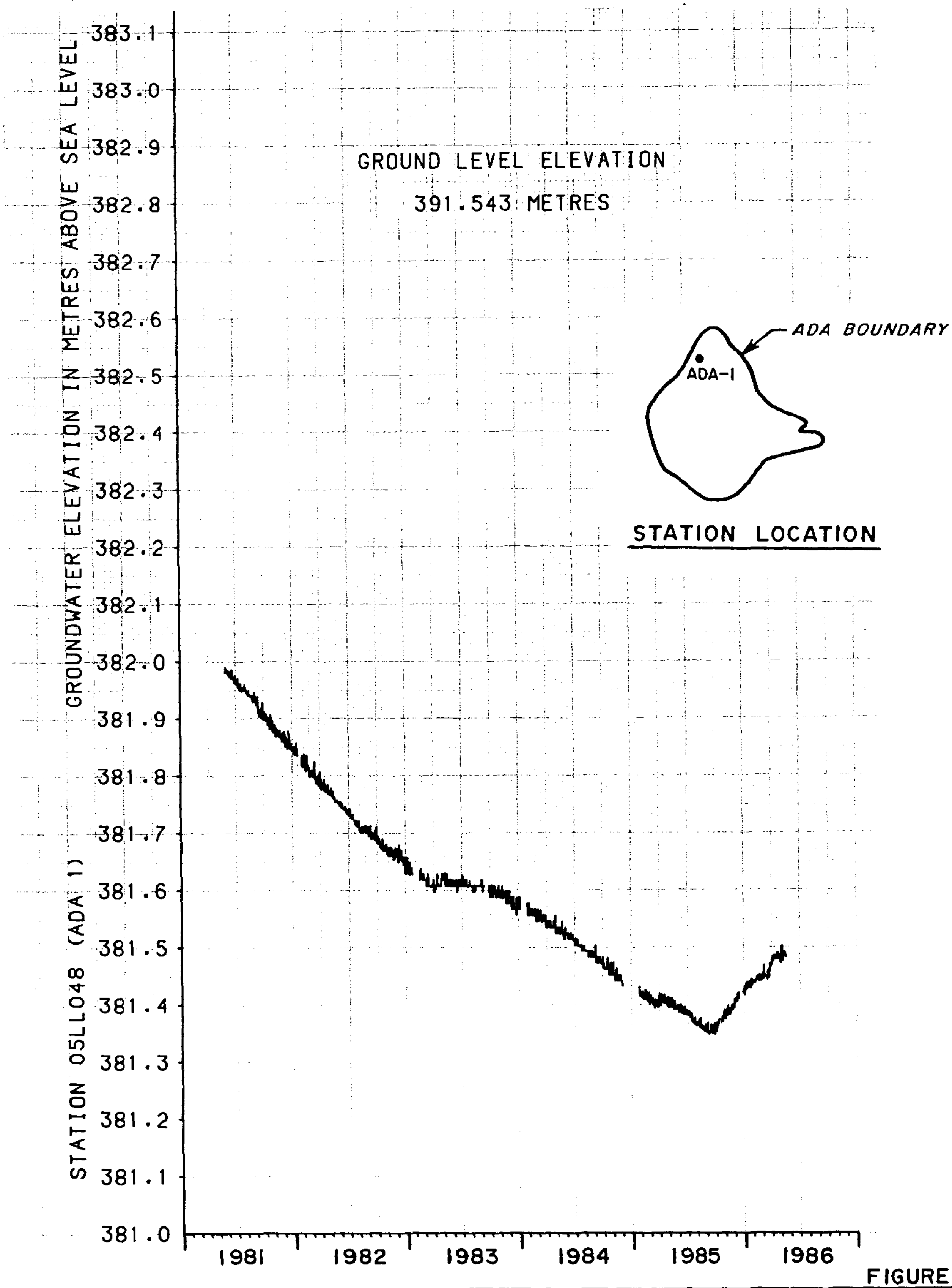


FIGURE 52

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

DRAWN M.M.	Manitoba Natural Resources Water Resources	ASSINIBOINE DELTA AQUIFER HYDROGRAPH FOR MONITORING STATION ADA-1
CHECKED		
PREPARED F.W. Render	SUBMITTED [signature] / APPROVED [signature]	SCALE AS SHOWN / DATE 86 06 27 / SHEET 52 OF 88 / FILE NO. 90-1-7-1141

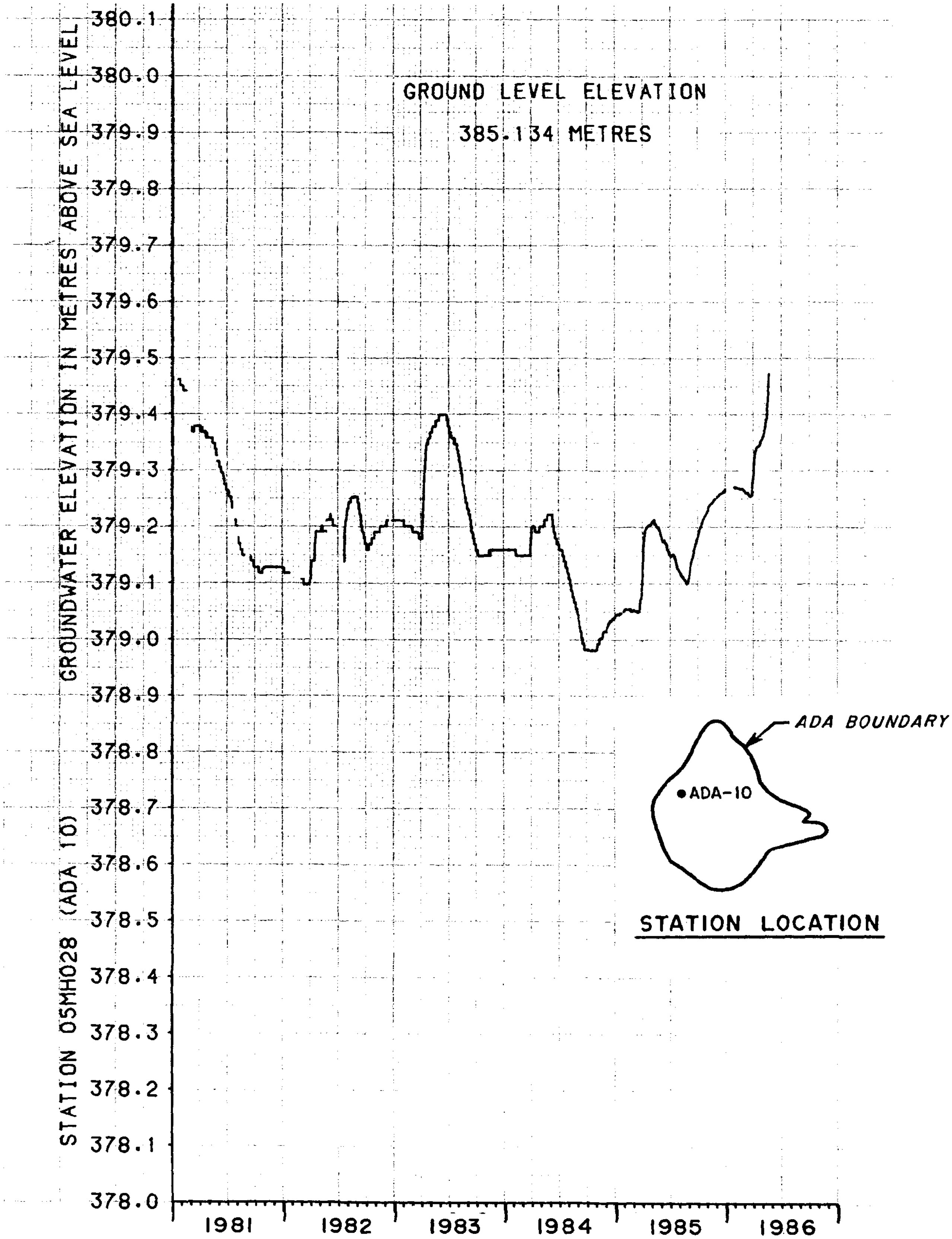


FIGURE 53

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

DRAWN M.M.	Manitoba Natural Resources Water Resources	ASSINIBOINE DELTA AQUIFER **HYDROGRAPH FOR MONITORING STATION ADA-10**
CHECKED		
PREPARED F.W. Render	SUBMITTED / APPROVED	SCALE AS SHOWN / DATE 86 06 27 / SHEET 53 OF 88 / FILE NO. 90-1-7-1141

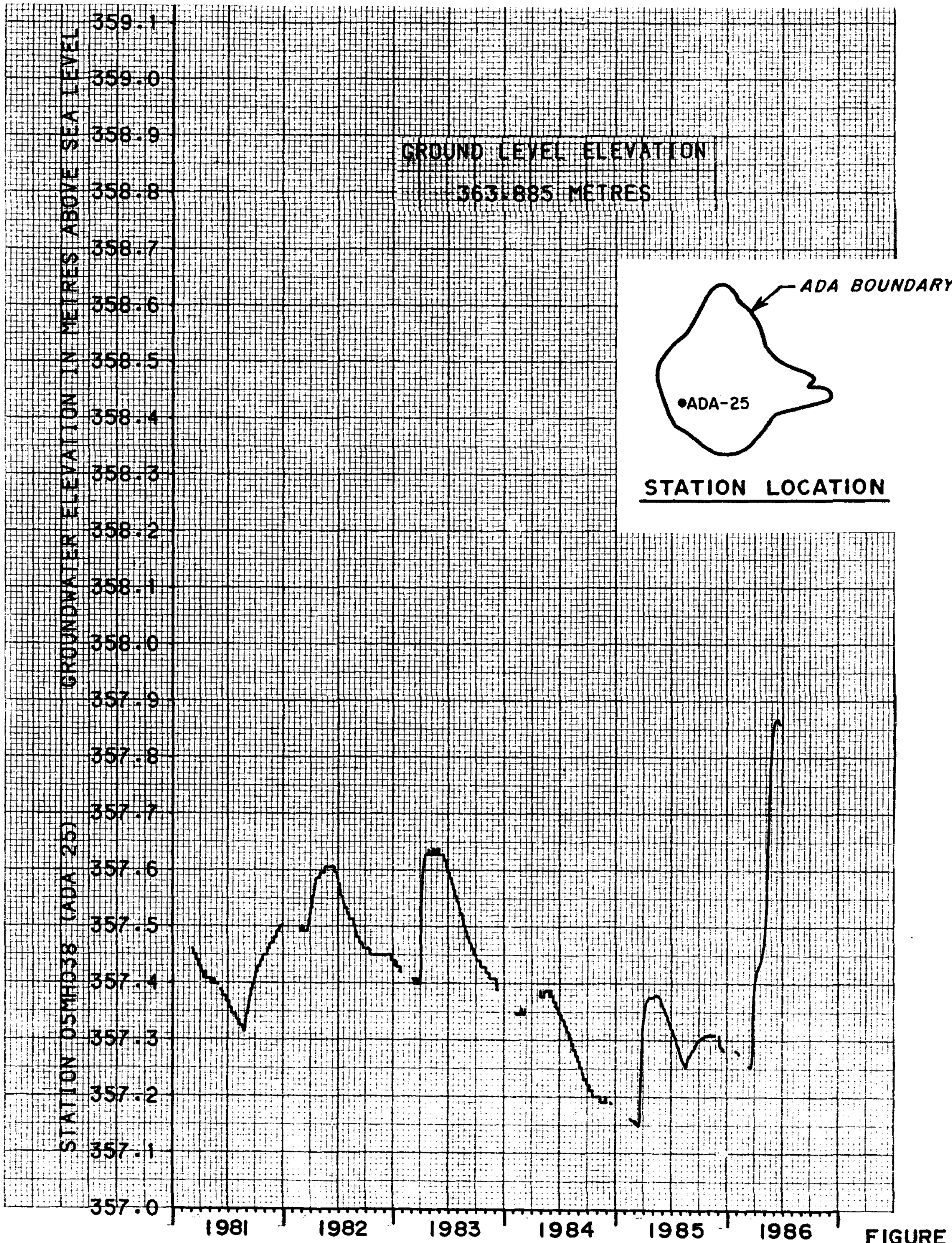


FIGURE 54

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

ASSINIBOINE DELTA AQUIFER

HYDROGRAPH FOR MONITORING STATION ADA-25

DRAWN M.M.	Manitoba Natural Resources	
CHECKED	Water Resources	
PREPARED F.W. Render	SUBMITTED	APPROVED

SCALE	DATE	SHEET	FILE NO.
AS SHOWN	86 06 27	54 OF 88	90-1-7-1141

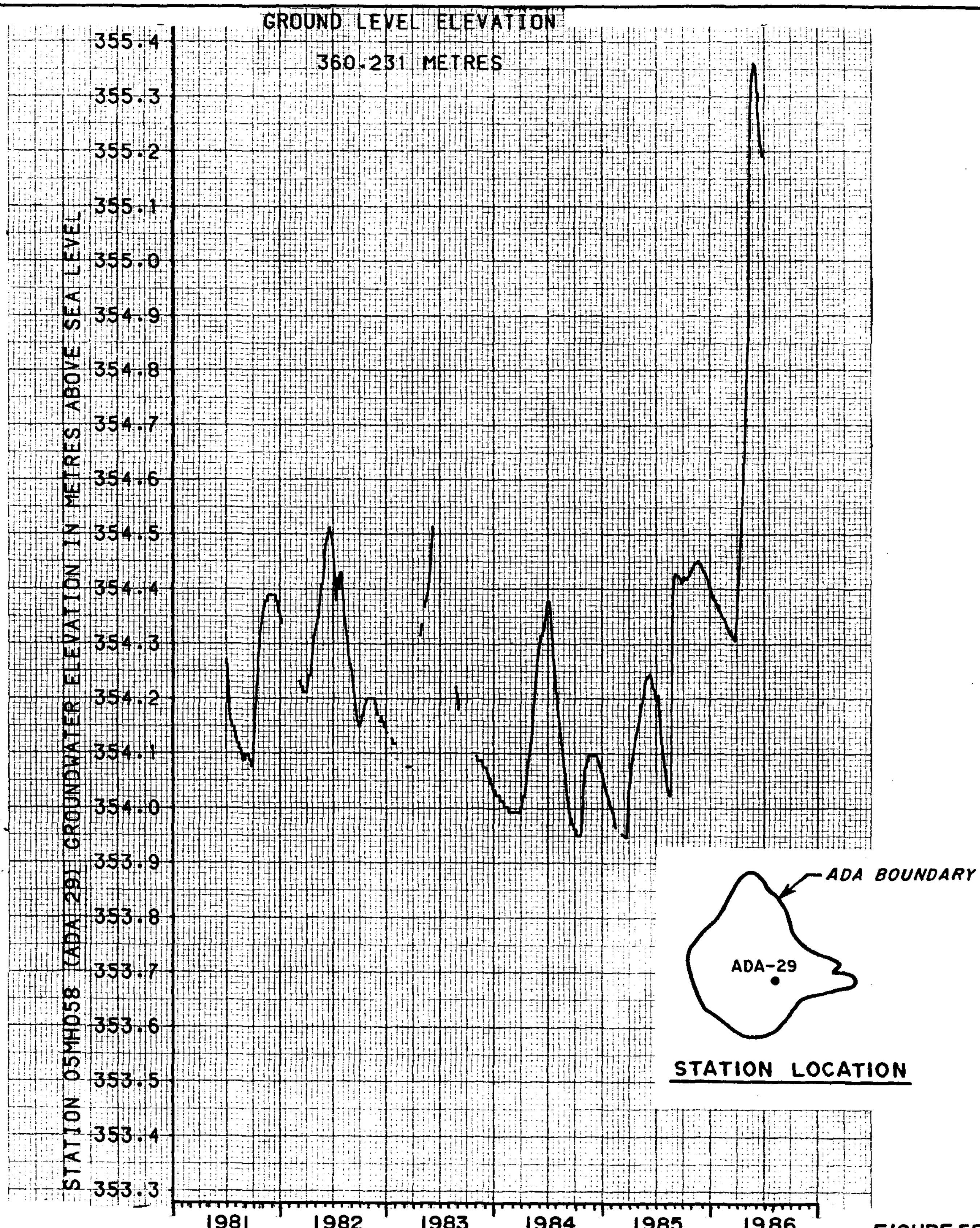


FIGURE 55

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

DRAWN M.M.	Manitoba Natural Resources Water Resources	ASSINIBOINE DELTA AQUIFER HYDROGRAPH FOR MONITORING STATION ADA-29
CHECKED		
PREPARED F.W. Render	SUBMITTED [signature] / APPROVED [signature]	SCALE AS SHOWN / DATE 86 06 27 / SHEET 55 OF 88 / FILE NO. 90-1-7-1141

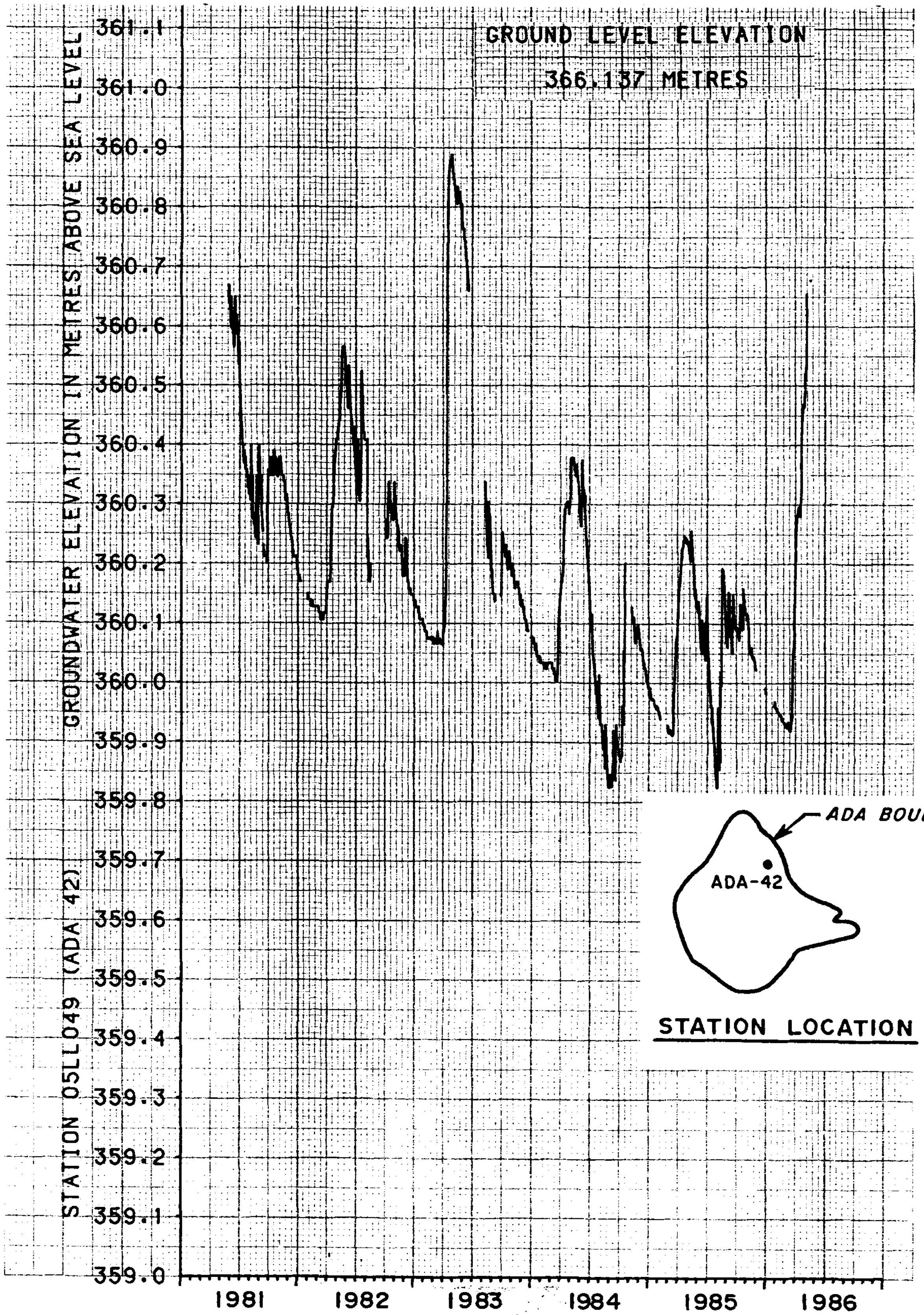
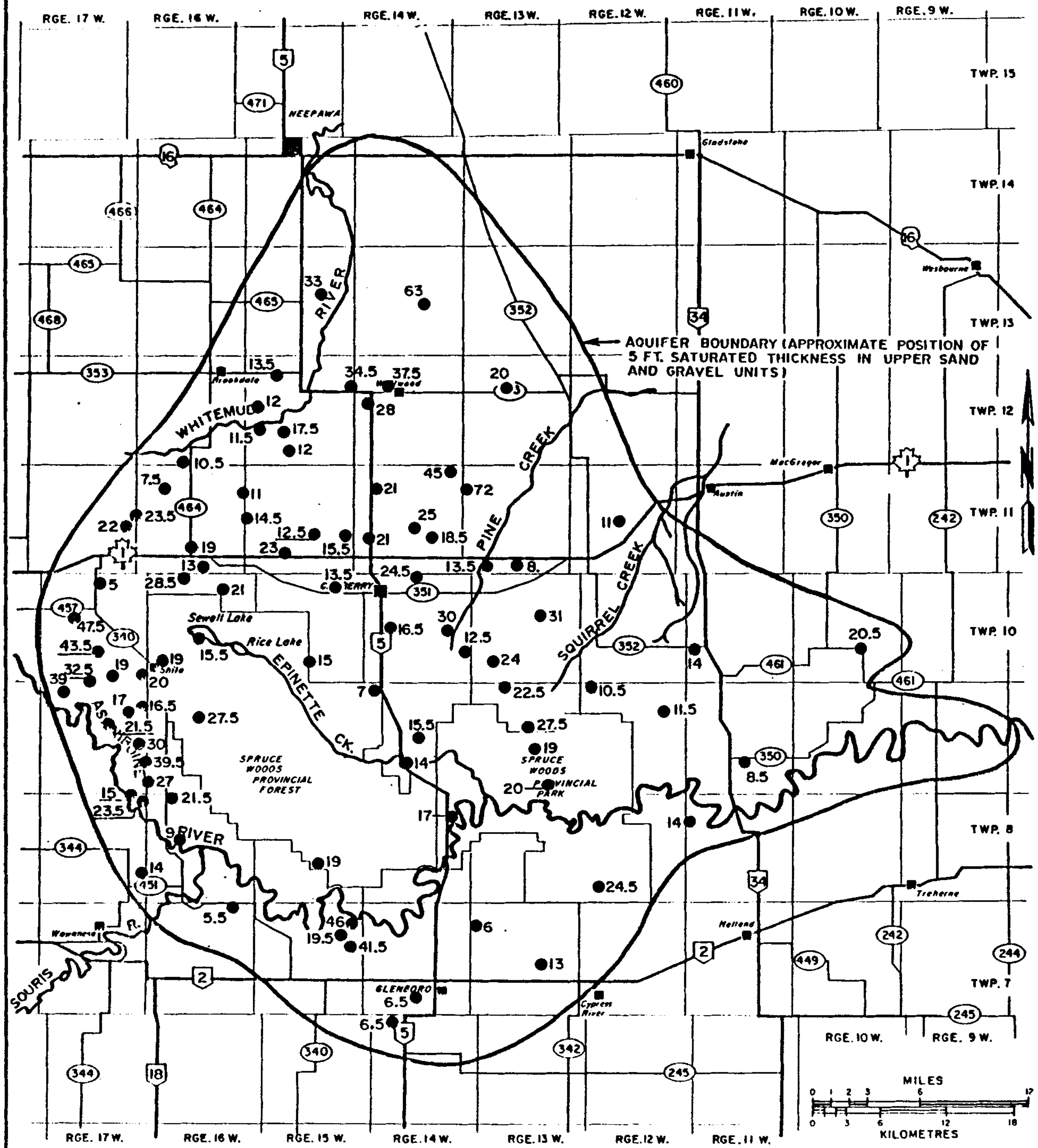


FIGURE 56

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

DRAWN M. M.	Manitoba Natural Resources Water Resources	ASSINIBOINE DELTA AQUIFER
CHECKED		HYDROGRAPH FOR MONITORING STATION ADA-42
PREPARED F.W. Render	SUBMITTED [signature] APPROVED [signature]	SCALE AS SHOWN · DATE 86 06 27 · SHEET 56 OF 88 · FILE NO. 90-1-7-1141



LEGEND

24.5 ● – MONITORING STATION WITH DEPTH TO WATER FROM GROUND LEVEL IN FEET

FIGURE 61

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 – AQUIFER CAPACITY INVESTIGATIONS

Manitoba Natural Resources
Water Resources

ASSINIBOINE DELTA AQUIFER

DEPTH TO WATER
JANUARY 1986

DRAWN F.B.R.	CHECKED	PREPARED W.H./F.W.R.	SUBMITTED	APPROVED
SCALE AS SHOWN	DATE 860627	SHEET 61 OF 88	FILE NO. 90-1-7-1141	

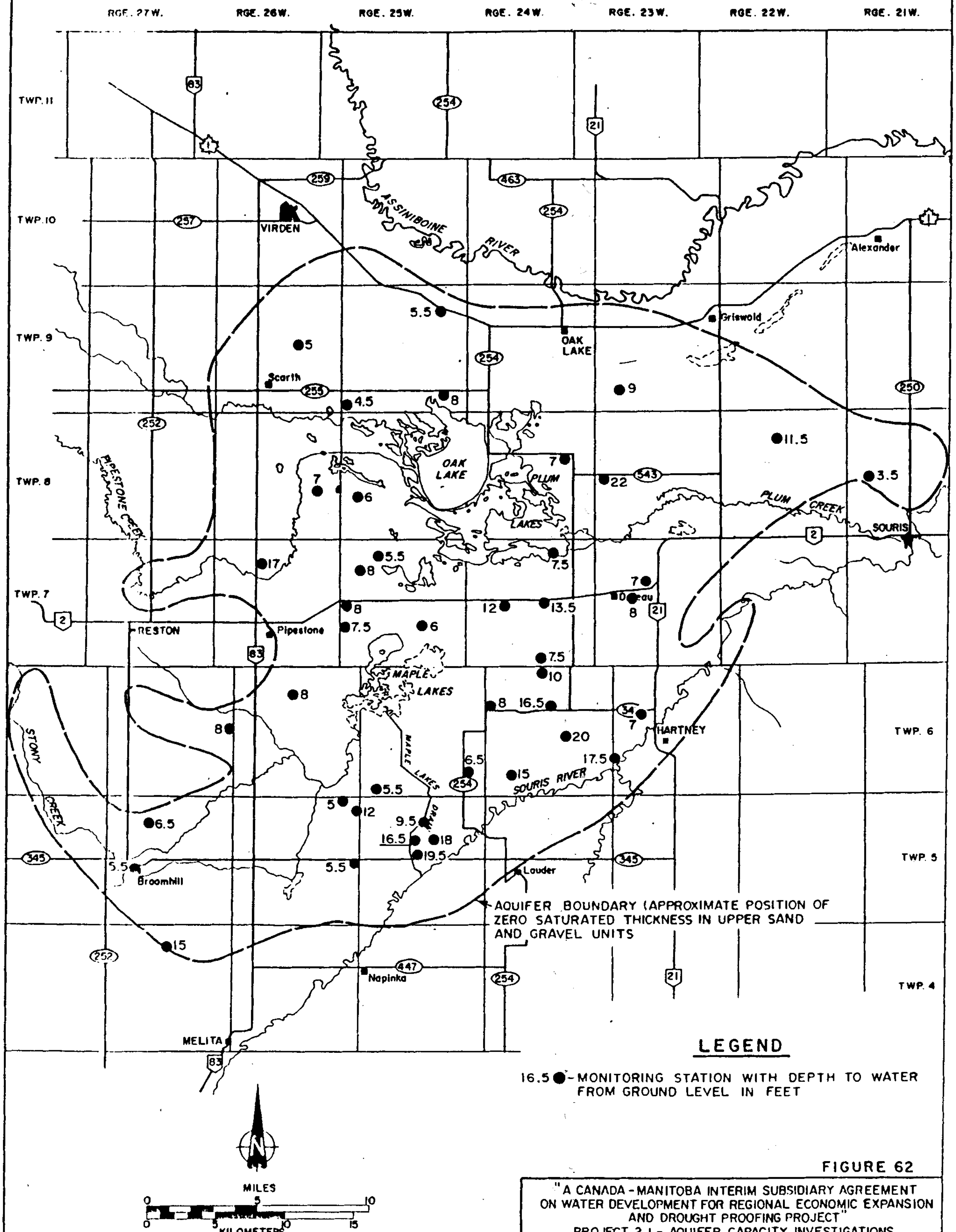
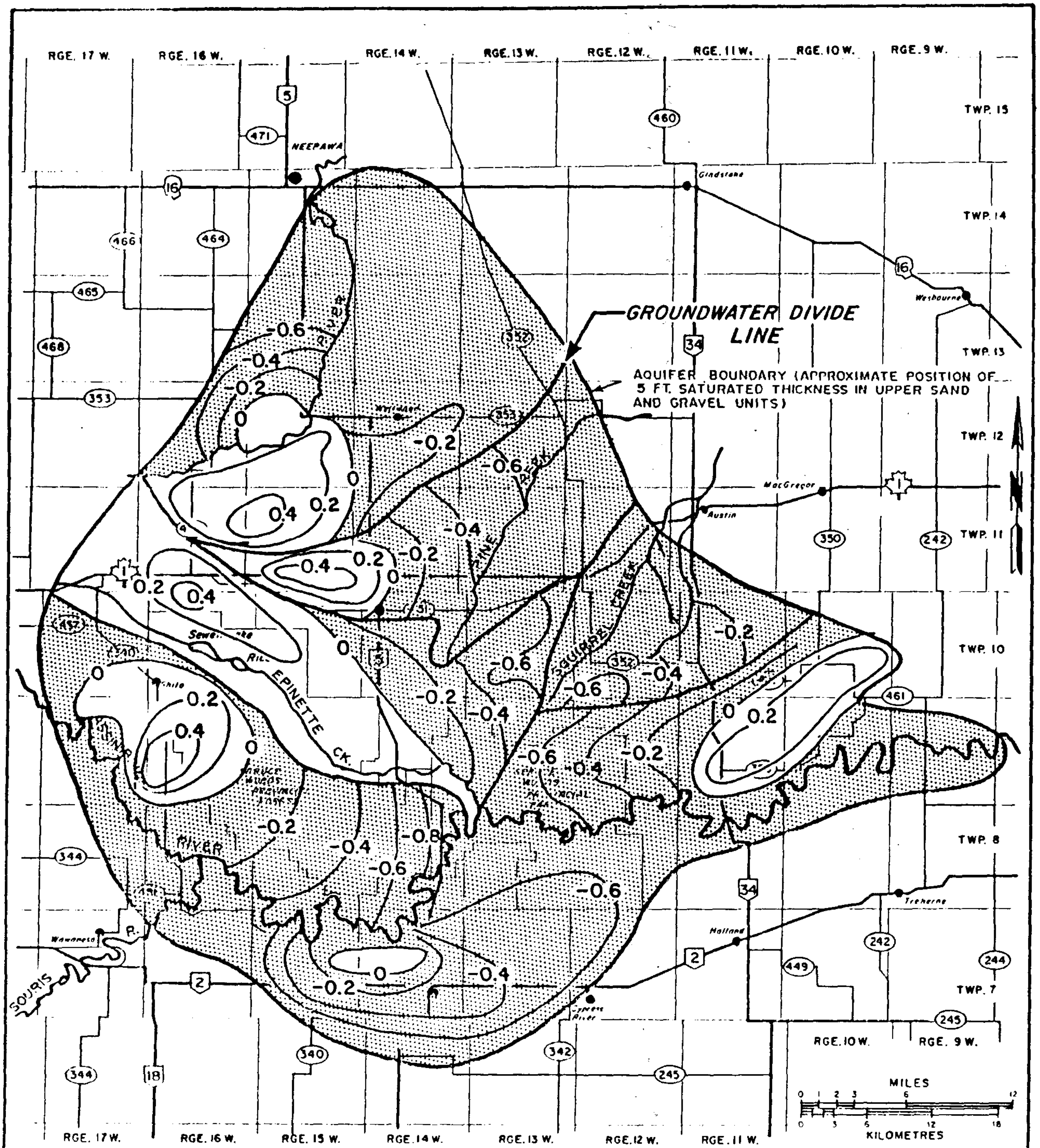


FIGURE 62

"A CANADA - MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

DRAWN F.B.R.	PROVINCE OF MANITOBA DEPARTMENT OF NATURAL RESOURCES WATER RESOURCES BRANCH	OAK LAKE AQUIFER **DEPTH TO WATER** JANUARY 1986
CHECKED		
PREPARED W.H./F.W.R.	SUBMITTED [signature] / APPROVED [signature]	SCALE AS SHOWN · DATE 86 06 27 · SHEET 62 OF 88 · FILE No. 90-1-7-1141



LEGEND

—0.4— CHANGE IN FEET

-0.2 — NET LOSS

FIGURE 63

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

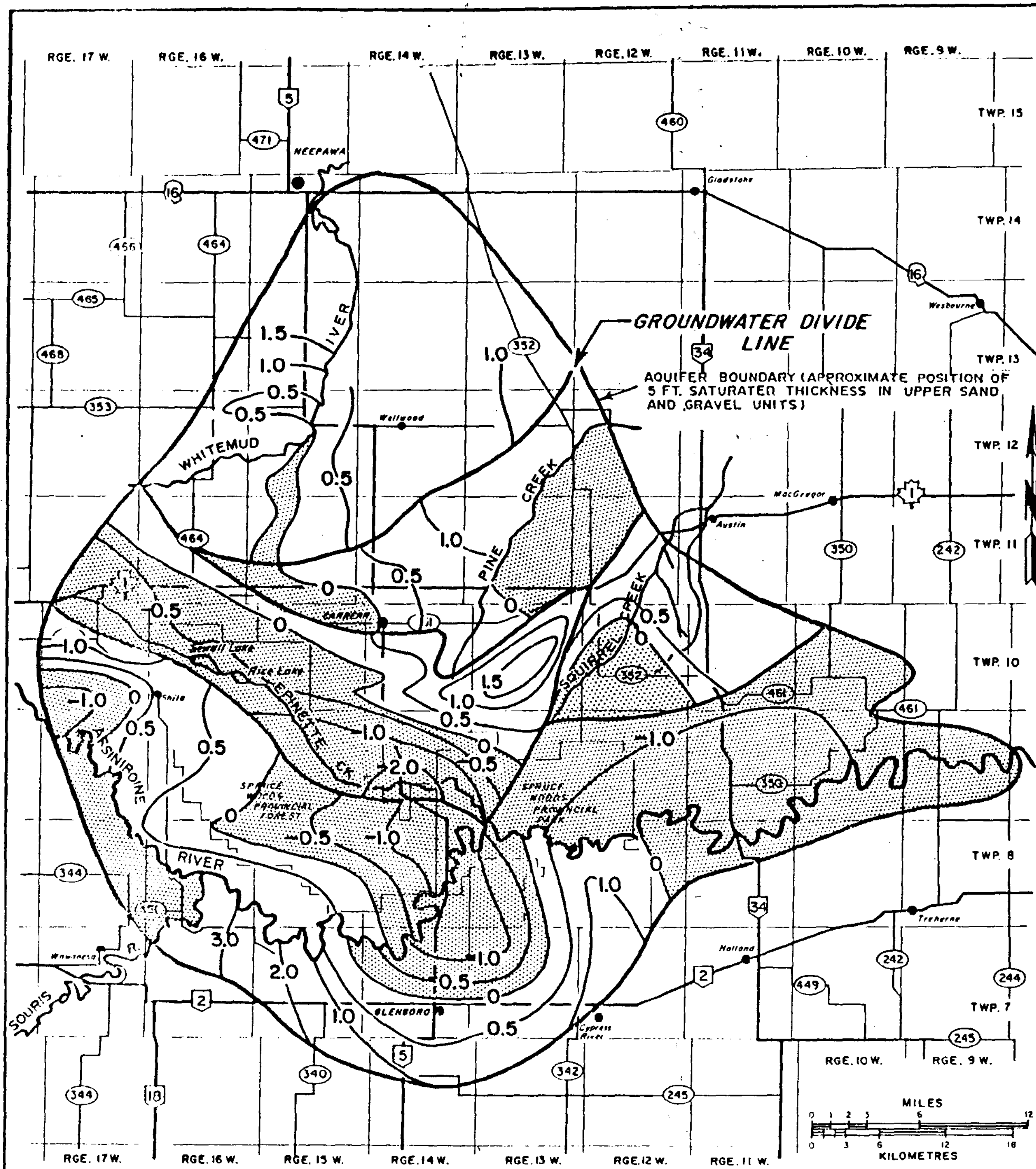
ASSINIBOINE DELTA AQUIFER

WATER TABLE CHANGE

NOVEMBER 1981 TO NOVEMBER 1982

Manitoba Natural Resources
Water Resources

DRAWN	CHECKED	PREPARED	SUBMITTED	APPROVED	SCALE	DATE	SHEET	FILE NO.
F.B.R.		W.H. / F.W.R.	[signature]	[signature]	AS SHOWN	86 06 27	63 OF 88	90-1-7-1141



LEGEND

—0.5— CHANGE IN FEET

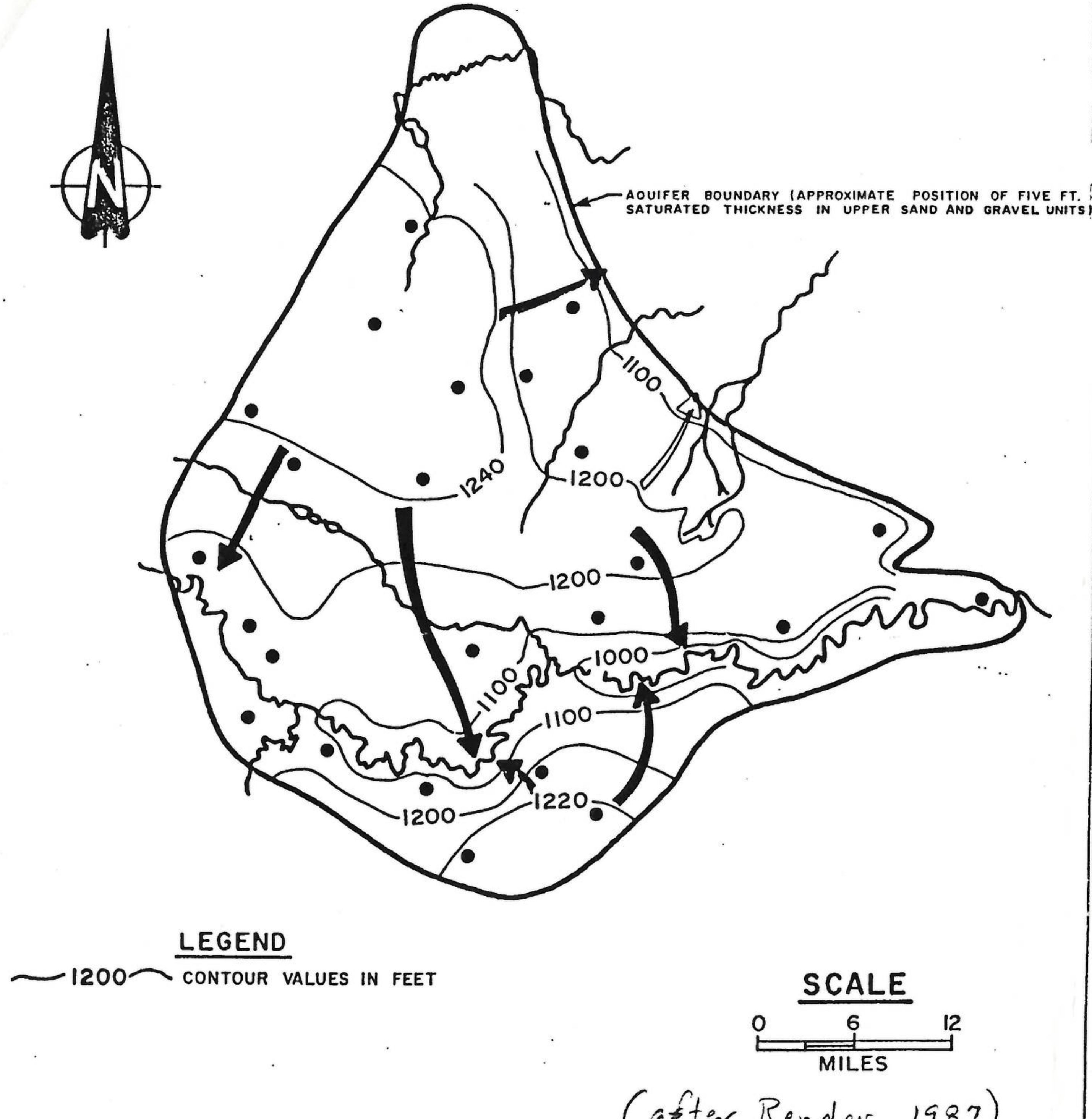
-1.0 — NET LOSS

FIGURE 64

"A CANADA–MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 – AQUIFER CAPACITY INVESTIGATIONS

DRAWN	Manitoba Natural Resources Water Resources	ASSINIBOINE DELTA AQUIFER
F.B.R.		**WATER TABLE CHANGE**
CHECKED		AUGUST 1981 TO AUGUST 1985
PREPARED	SUBMITTED	APPROVED
W.H. / F.W.R.		

SCALE	DATE	SHEET	FILE NO.
AS SHOWN	86 06 27	64 OF 88	90-1-7-1141



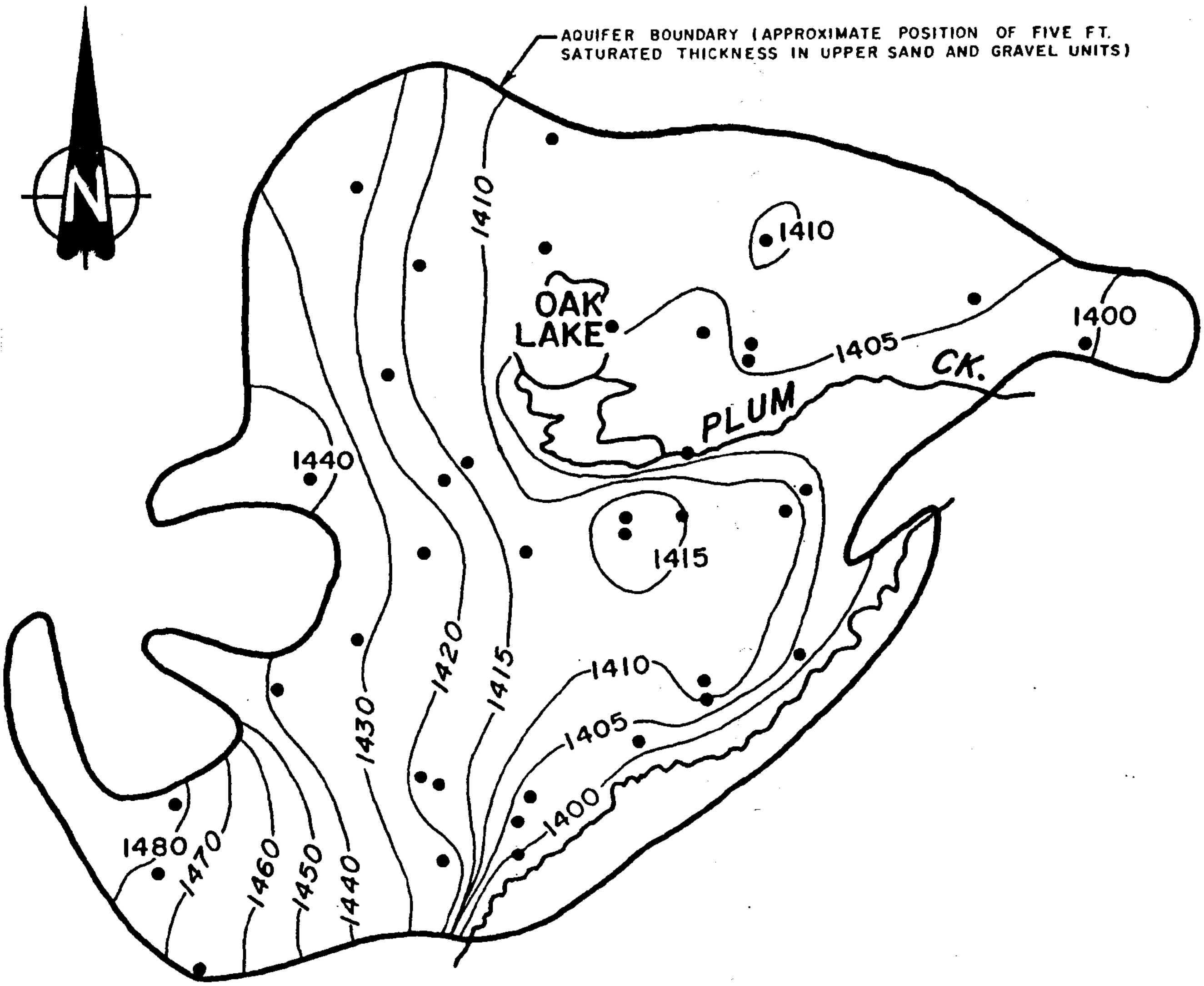
(after Render, 1987)

FIGURE 65

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

DRAWN F. B. R.	Manitoba Natural Resources Water Resources	ASSINIBOINE DELTA AQUIFER POTENTIOMETRIC SURFACE
CHECKED		
PREPARED W.H./F.W.R.	SUBMITTED [signature] / APPROVED [signature]	SCALE AS SHOWN / DATE 86 06 27 / SHEET 65 OF 88 / FILE NO. 90-1-7-1141



SCALE

0 6 12

MILES

LEGEND

1400 CONTOUR VALUES IN FEET

FIGURE 66

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

OAK LAKE AQUIFER

POTENTIOMETRIC SURFACE

Manitoba Natural Resources

Water Resources

DRAWN F. B. R.	CHECKED	PREPARED W.H. / F.W.R.	SUBMITTED
APPROVED	SCALE AS SHOWN	DATE 860627	SHEET 66 OF 88
FILE NO. 90-1-7-1141			

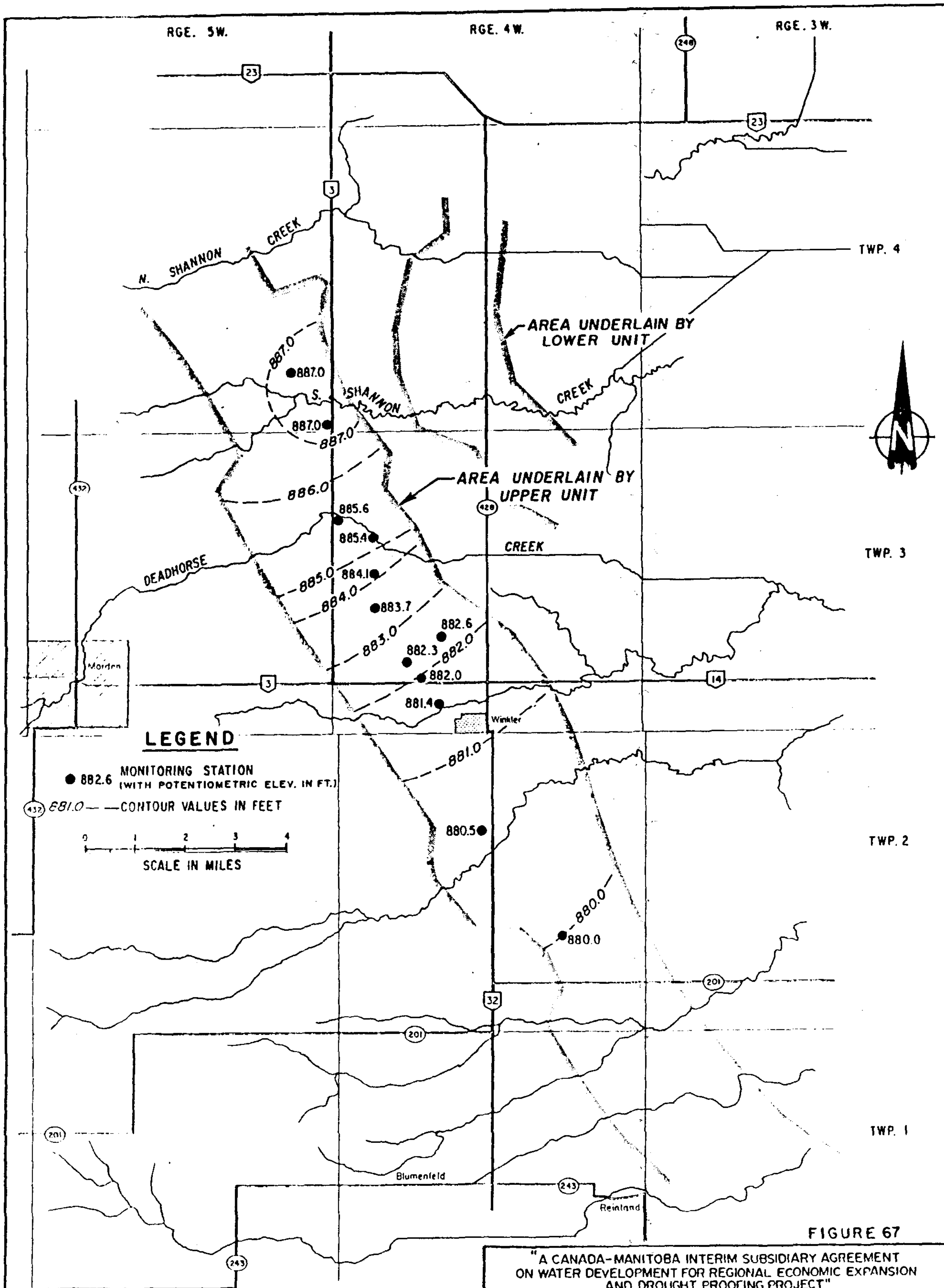


FIGURE 67

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

Manitoba Natural Resources
Water Resources

WINKLER AQUIFER

POTENTIOMETRIC SURFACE

JANUARY 1986

DRAWN F.B.R.	SUBMITTED	APPROVED	SCALE AS SHOWN	DATE 86 06 27
CHECKED			SHEET 67 OF 88	FILE NO. 90-1-7-1141
PREPARED W.H. / E.W.R.				

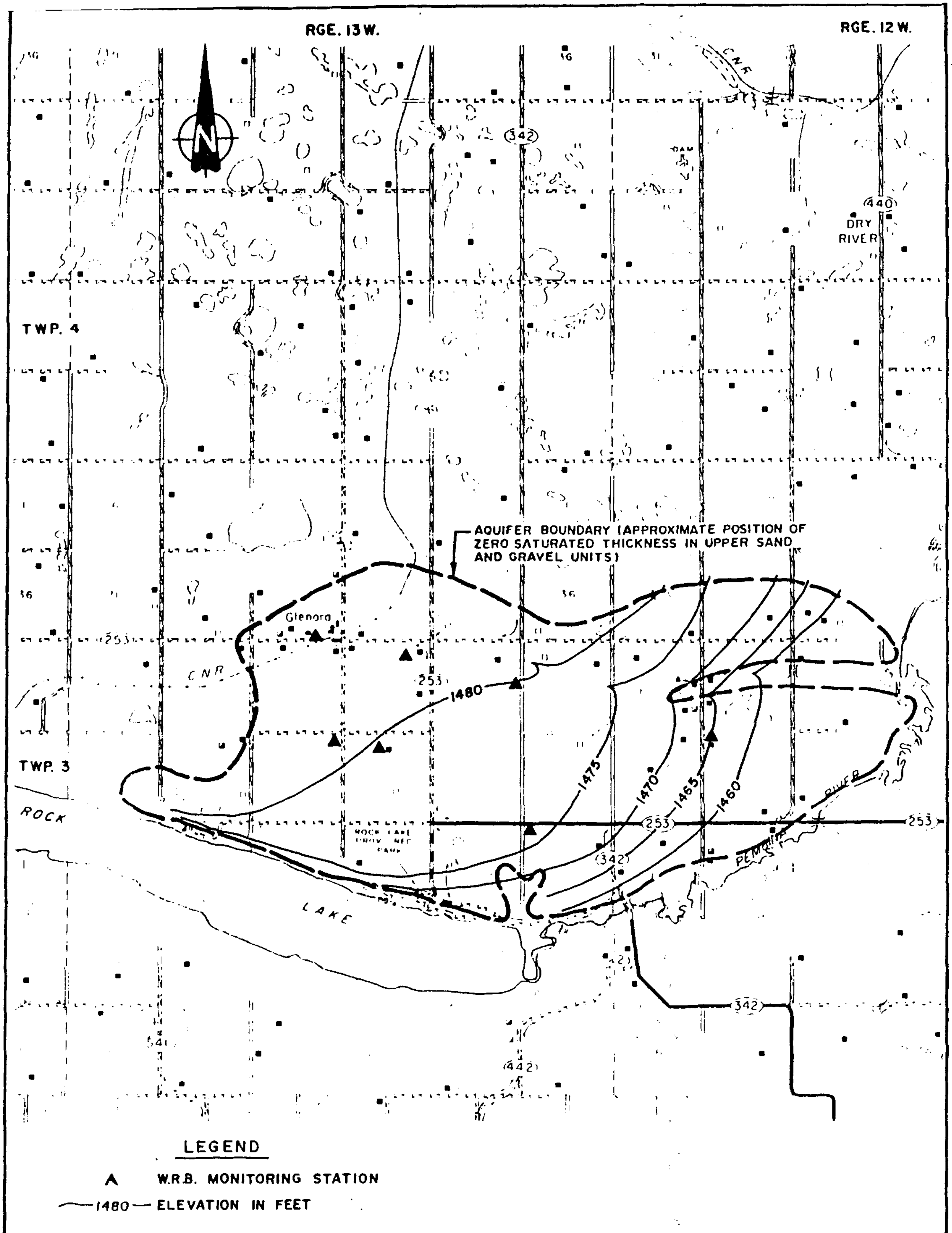


FIGURE 68

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 – AQUIFER CAPACITY INVESTIGATIONS

DRAWN F.B.R.	Manitoba Natural Resources Water Resources	GLENORA AQUIFER
CHECKED		**POTENTIOMETRIC SURFACE 1985**
PREPARED F.W. Render	SUBMITTED / APPROVED	SCALE AS SHOWN · DATE 86 06 27 · SHEET 68 OF 88 · FILE NO. 90-1-7-1141

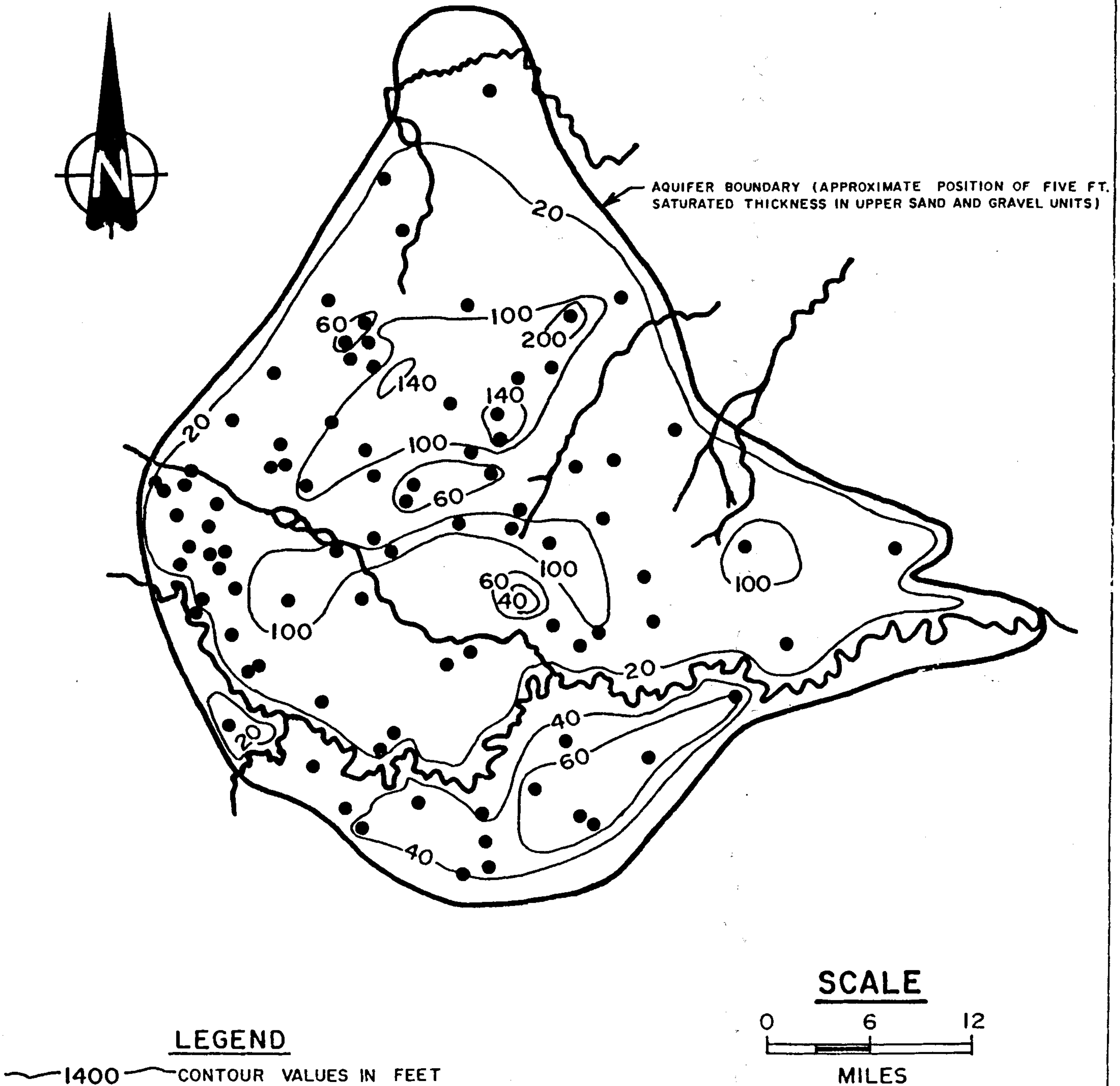


FIGURE 69

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

Manitoba Natural Resources
Water Resources

ASSINIBOINE DELTA AQUIFER

SAND AND GRAVEL THICKNESS

DRAWN: F.B.R.	CHECKED:	PREPARED: F.W. Render

SUBMITTED	APPROVED	SCALE	DATE	SHEET	FILE NO.
[signature]	[signature]	AS SHOWN	86 06 27	69 OF 88	90-1-7-1141

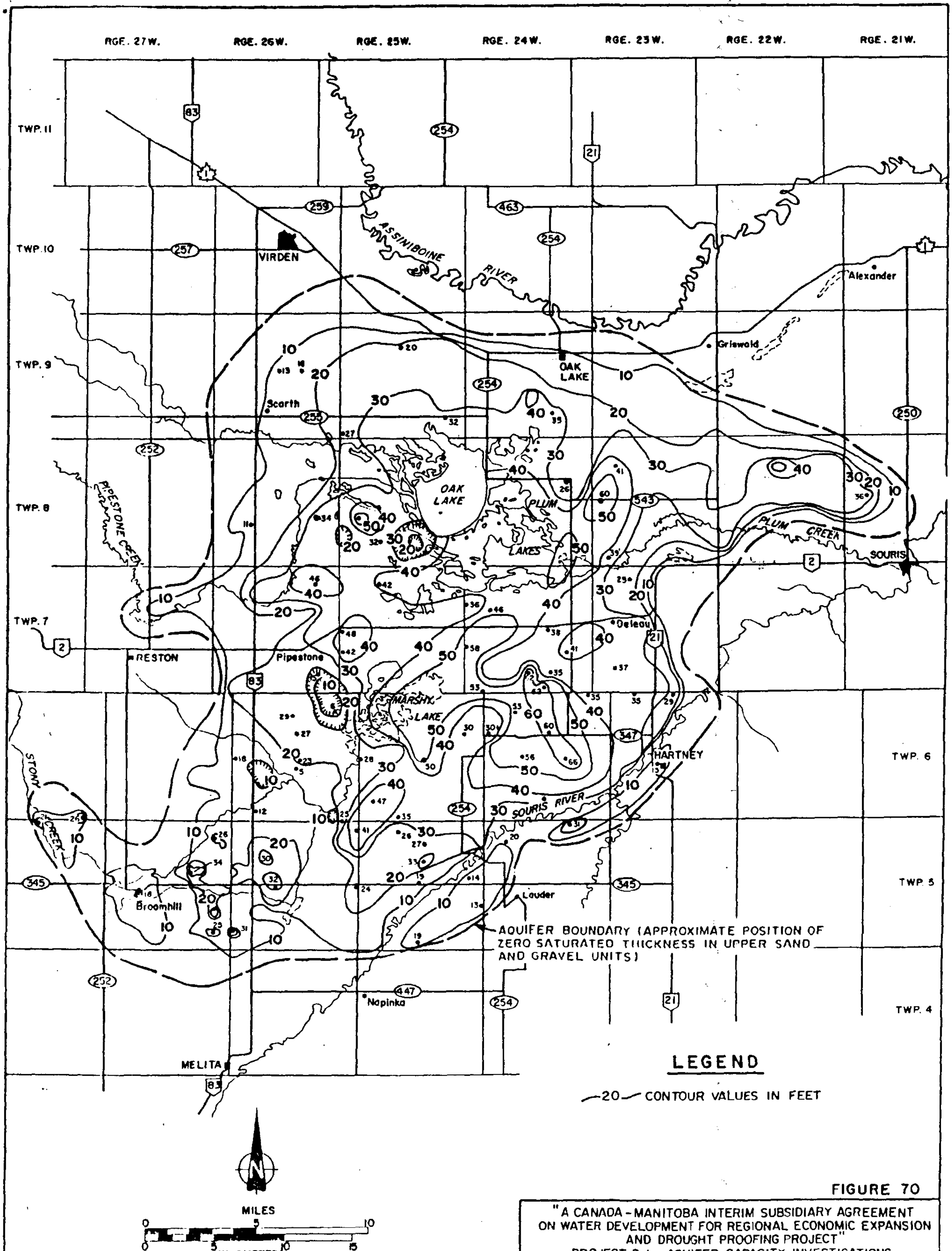


FIGURE 70

"A CANADA - MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

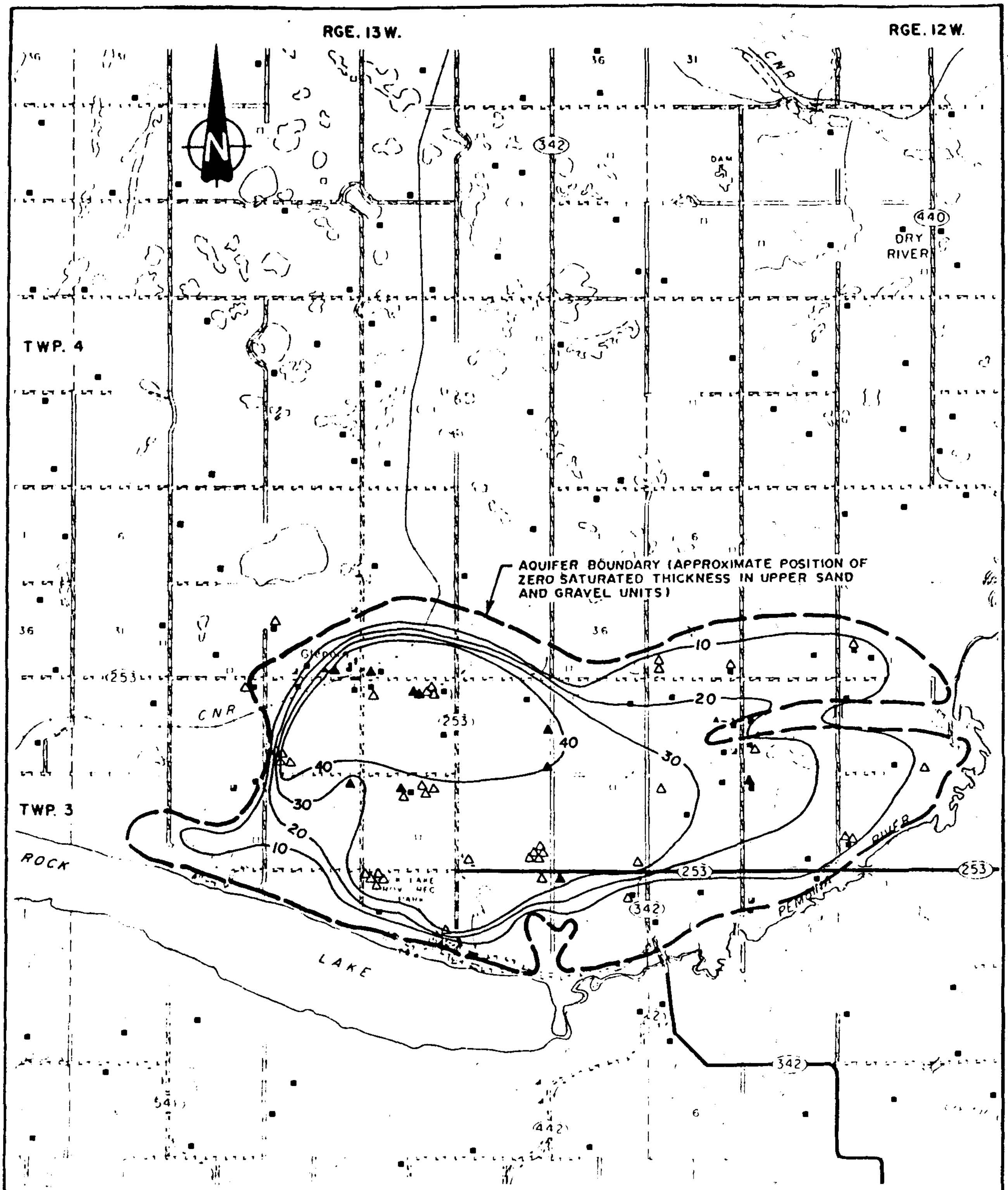
OAK LAKE AQUIFER

SAND AND GRAVEL THICKNESS

PROVINCE OF MANITOBA
DEPARTMENT OF NATURAL RESOURCES
WATER RESOURCES BRANCH

DRAWN	CHECKED	PREPARED	SUBMITTED	APPROVED
F.B.R.		F.W. Render	[signature]	[signature]

SCALE	DATE	SHEET	FILE No
AS SHOWN	86 06 27	70 OF 99	90-1-7-1141



▲ W.R.B. TEST HOLES

△ WELL DRILLERS LOGS

——10—— VALUES IN FEET

FIGURE 71

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 – AQUIFER CAPACITY INVESTIGATIONS

DRAWN F.B.R.	Manitoba Natural Resources Water Resources	GLENORA AQUIFER
CHECKED		SAND & GRAVEL THICKNESS
PREPARED F.W. Render	SUBMITTED / APPROVED	SCALE AS SHOWN · DATE 86 06 27 · SHEET 71 OF 88 · FILE NO. 90-1-7-1141

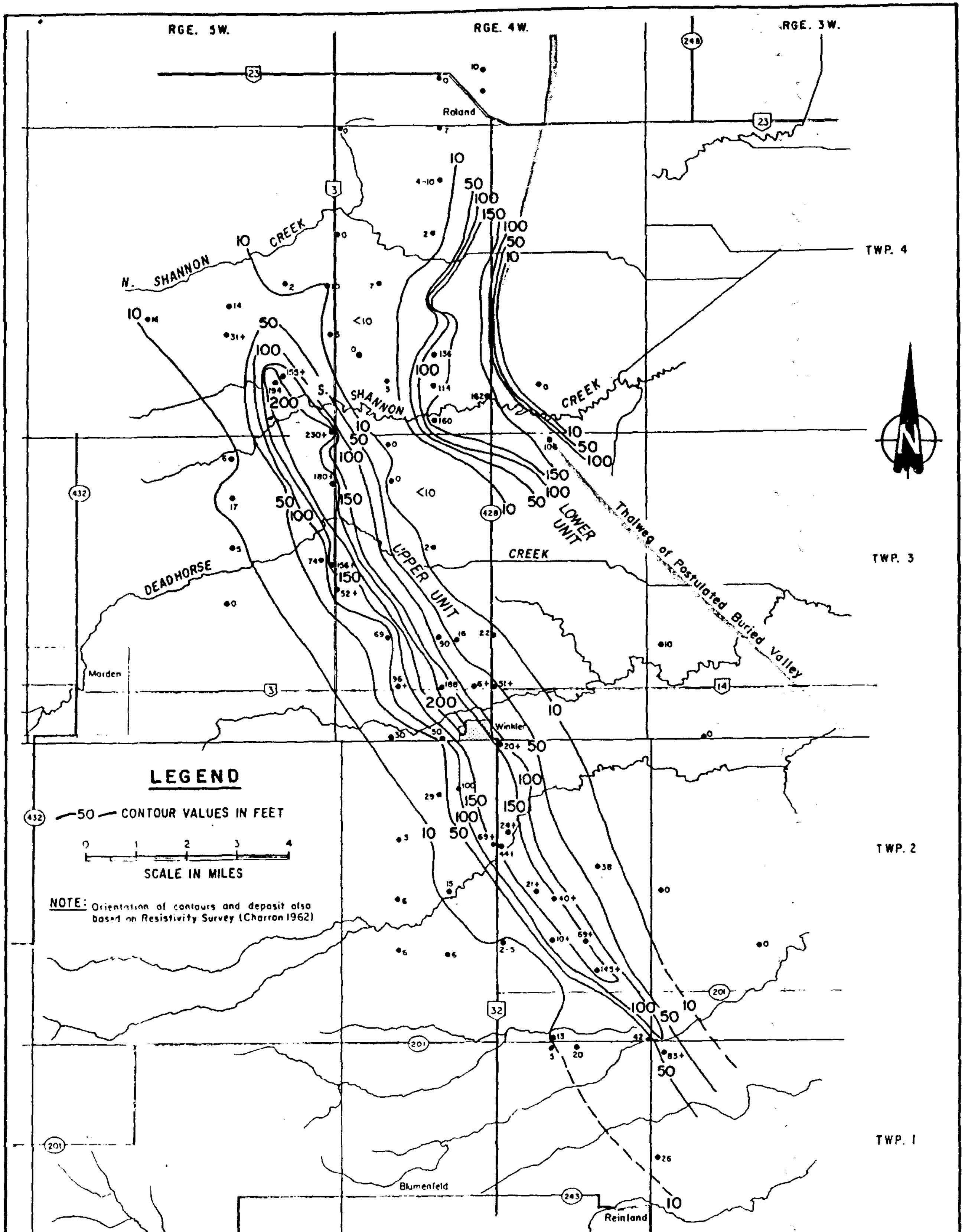
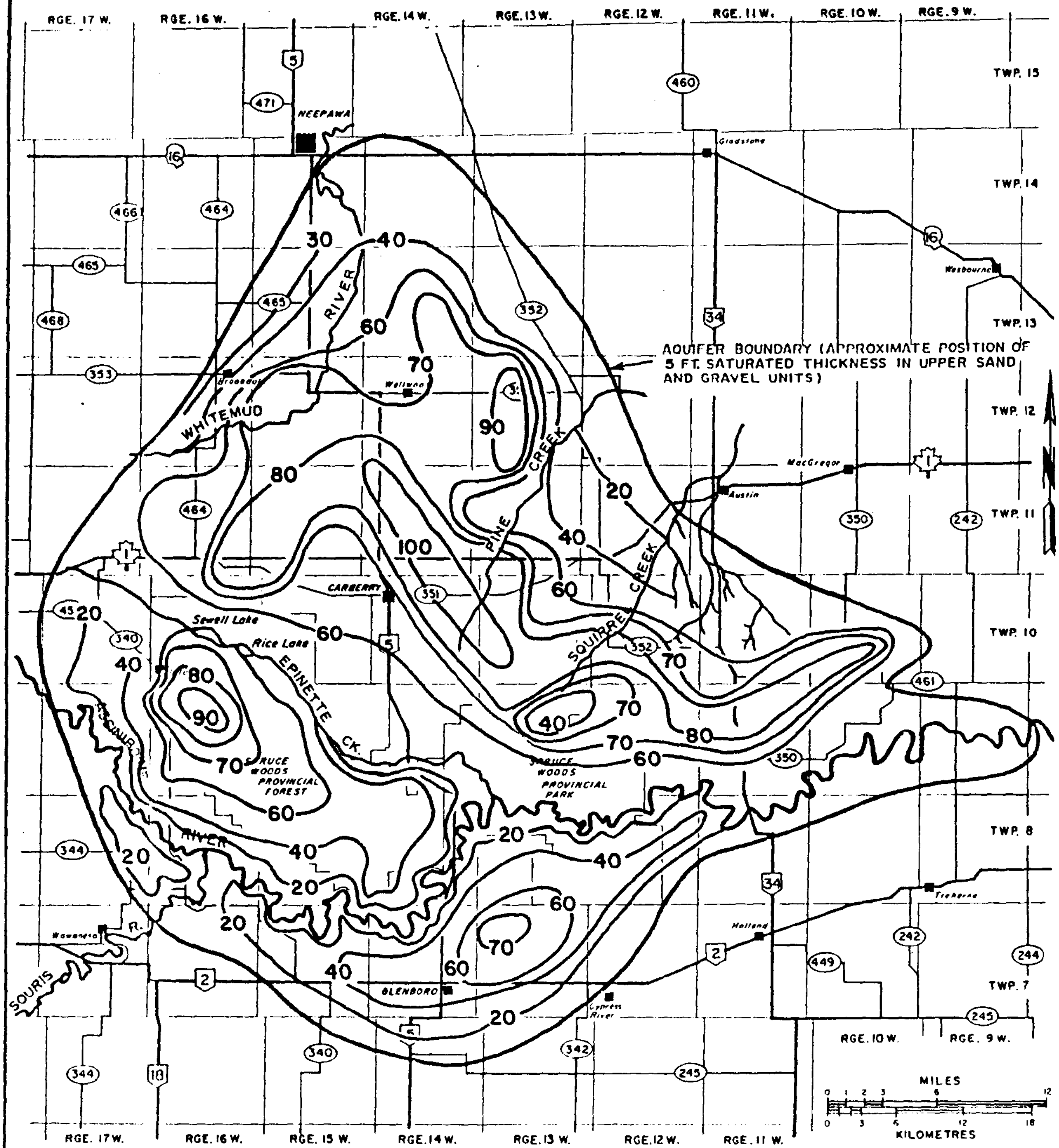


FIGURE 72

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

DRAWN F.B.R.	Manitoba Natural Resources	WINKLER AQUIFER
CHECKED	Water Resources	SAND AND GRAVEL THICKNESS
PREPARED F.W. Render	SUBMITTED / APPROVED	SCALE AS SHOWN · DATE 86 06 27 · SHEET 72 OF 88 · FILE NO. 90-1-7-1141



LEGEND

—40— VALUES IN FEET

FIGURE 73

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

ASSINIBOINE DELTA AQUIFER

UPPER SAND SATURATED THICKNESS

DRAWN	Manitoba Natural Resources Water Resources	
F.B.R.		
CHECKED		
PREPARED	SUBMITTED	APPROVED
F.W. Render		

SCALE	DATE	SHEET	FILE NO.
AS SHOWN	86 06 27	73 OF 88	90-1-7-1141

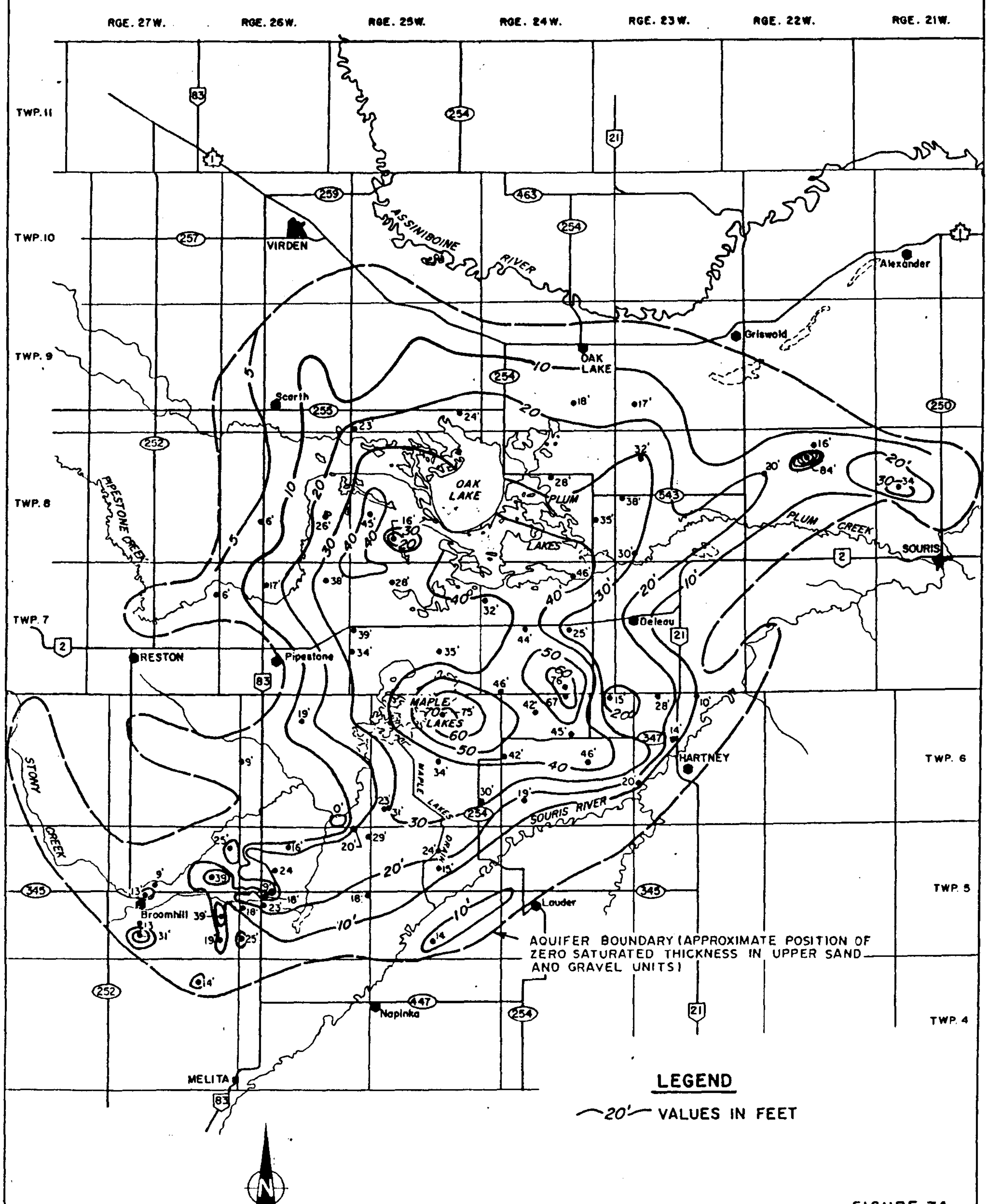


FIGURE 74

"A CANADA - MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

DRAWN F.B.R.	PROVINCE OF MANITOBA DEPARTMENT OF NATURAL RESOURCES WATER RESOURCES BRANCH	OAK LAKE AQUIFER SATURATED THICKNESS
CHECKED	SUBMITTED	APPROVED
PREPARED F.W. Render		

SCALE	DATE	SHEET	FILE No.
AS SHOWN	86 06 27	74 OF 88	90-1-7-1141

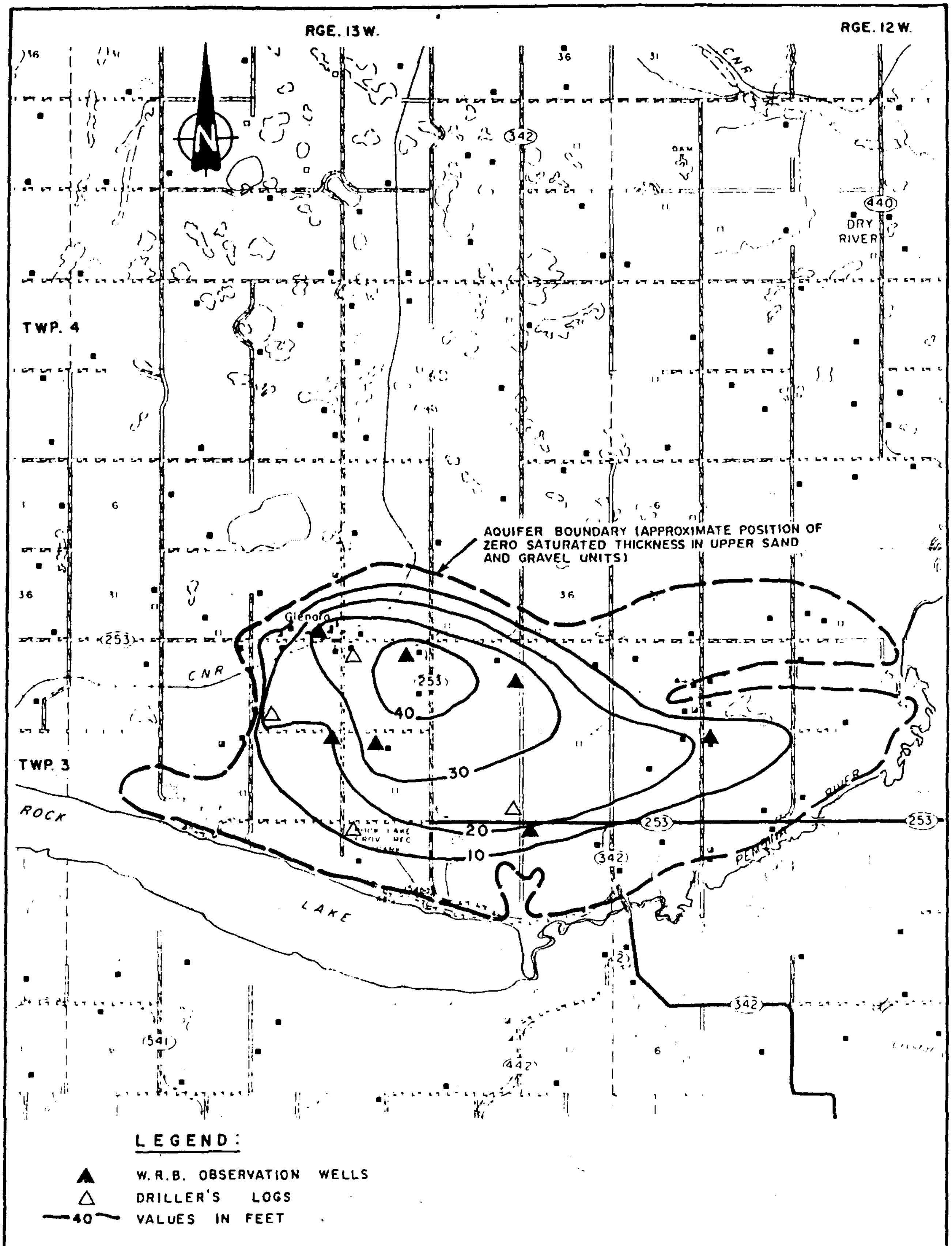


FIGURE 75

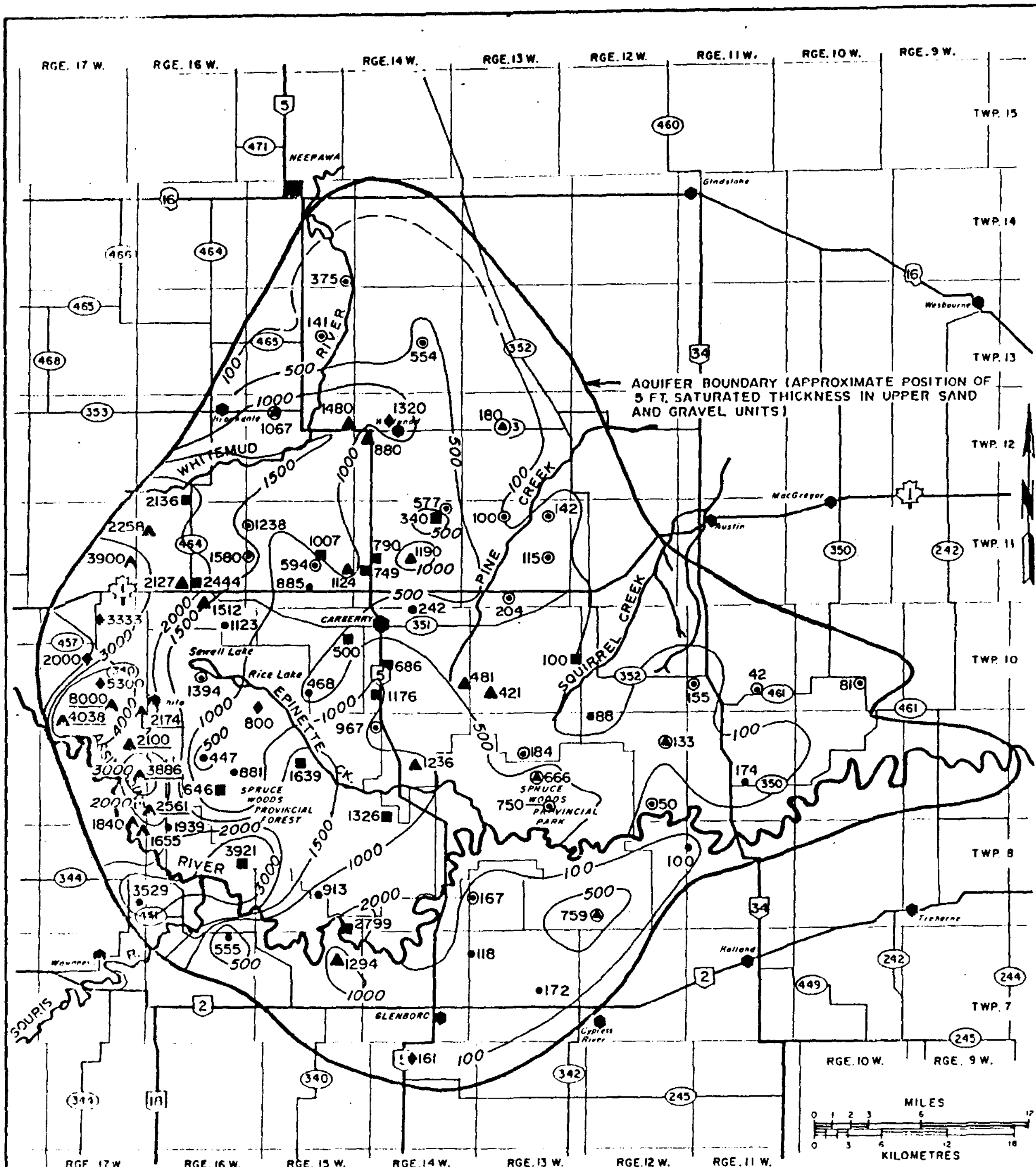
"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

Manitoba Natural Resources
Water Resources

GLENORA AQUIFER

SATURATED THICKNESS

DRAWN	CHECKED	PREPARED	SUBMITTED	APPROVED	SCALE	DATE	SHEET	FILE NO.
M. Manalastas		F.W. Render	[signature]	[signature]	AS SHOWN	86 06 27	75 OF 88	90-1-7-1141



ANALYTICAL METHOD

- (▲) – FORMAL MULTIWELL PUMPING TEST
- ▲ – MULTIWELL PUMPING TEST
- ● – SINGLE WELL PUMPING TEST
- ■ – SPECIFIC CAPACITY
- ◉ – GRAIN SIZE
- ◆ – HYDRAULIC CONDUCTIVITY – Interpreted from Transmissivity and Saturated Thickness maps.

Values in U.S. GALS./FT.^{2}/ DAY

FIGURE 76

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 – AQUIFER CAPACITY INVESTIGATIONS

Manitoba Natural Resources
Water Resources

ASSINIBOINE DELTA AQUIFER

HYDRAULIC CONDUCTIVITY

DRAWN	CHECKED	PREPARED	SUBMITTED	APPROVED	SCALE	DATE	SHEET	FILE NO.
F.B.R.		W.H. / E.W.R.	[signature]		AS SHOWN	86 06 27	76 OF 88	90-1-7-1141

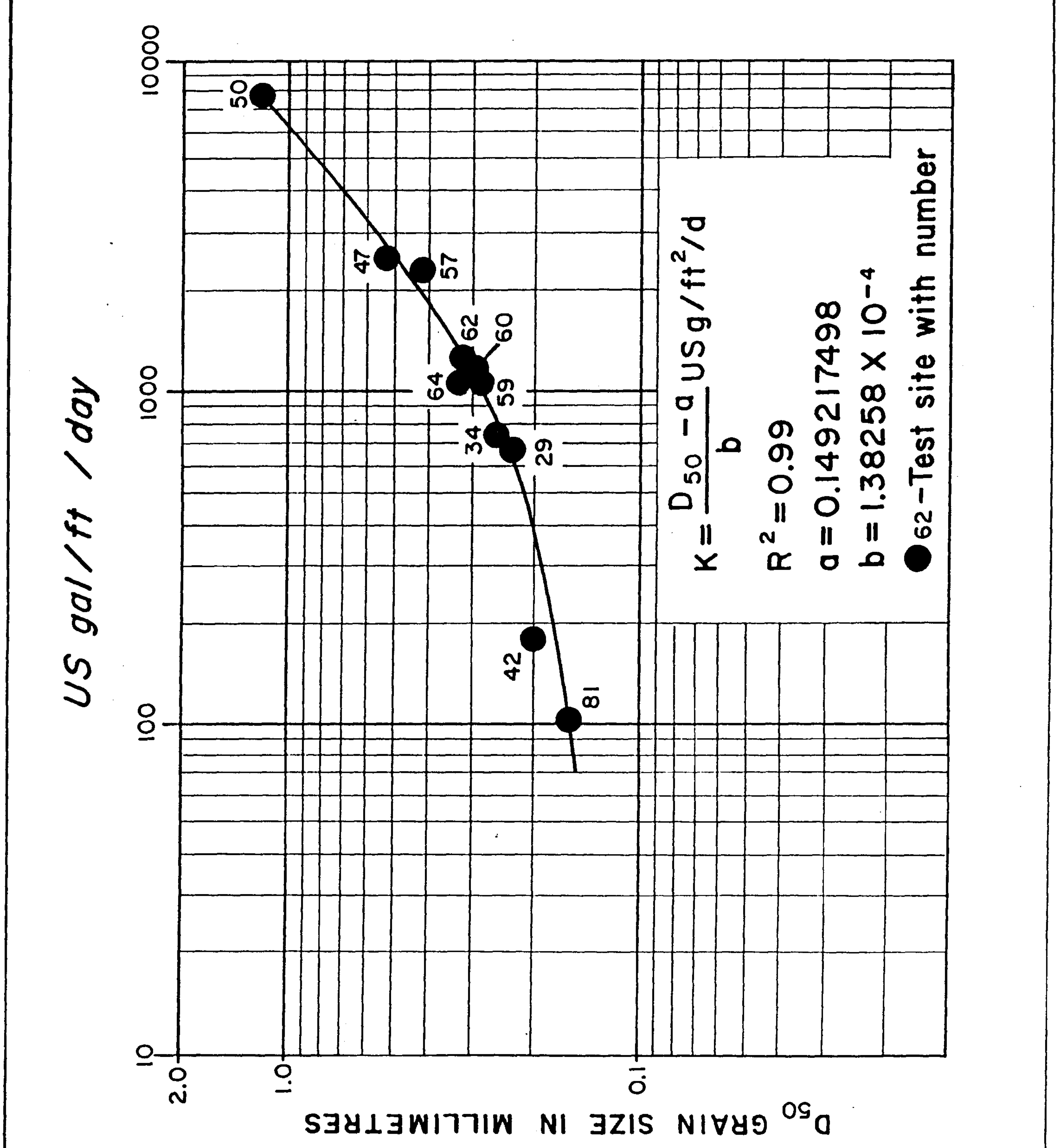


FIGURE 77

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

ASSINIBOINE DELTA AQUIFER

RELATION GRAIN SIZE TO HYDRAULIC CONDUCTIVITY

DRAWN F.B.R.	Manitoba Natural Resources Water Resources		
CHECKED			
PREPARED F.W. Render	SUBMITTED	APPROVED	
SCALE AS SHOWN	DATE 86 06 27	SHEET 77 OF 88	FILE NO. 90-1-7-1141

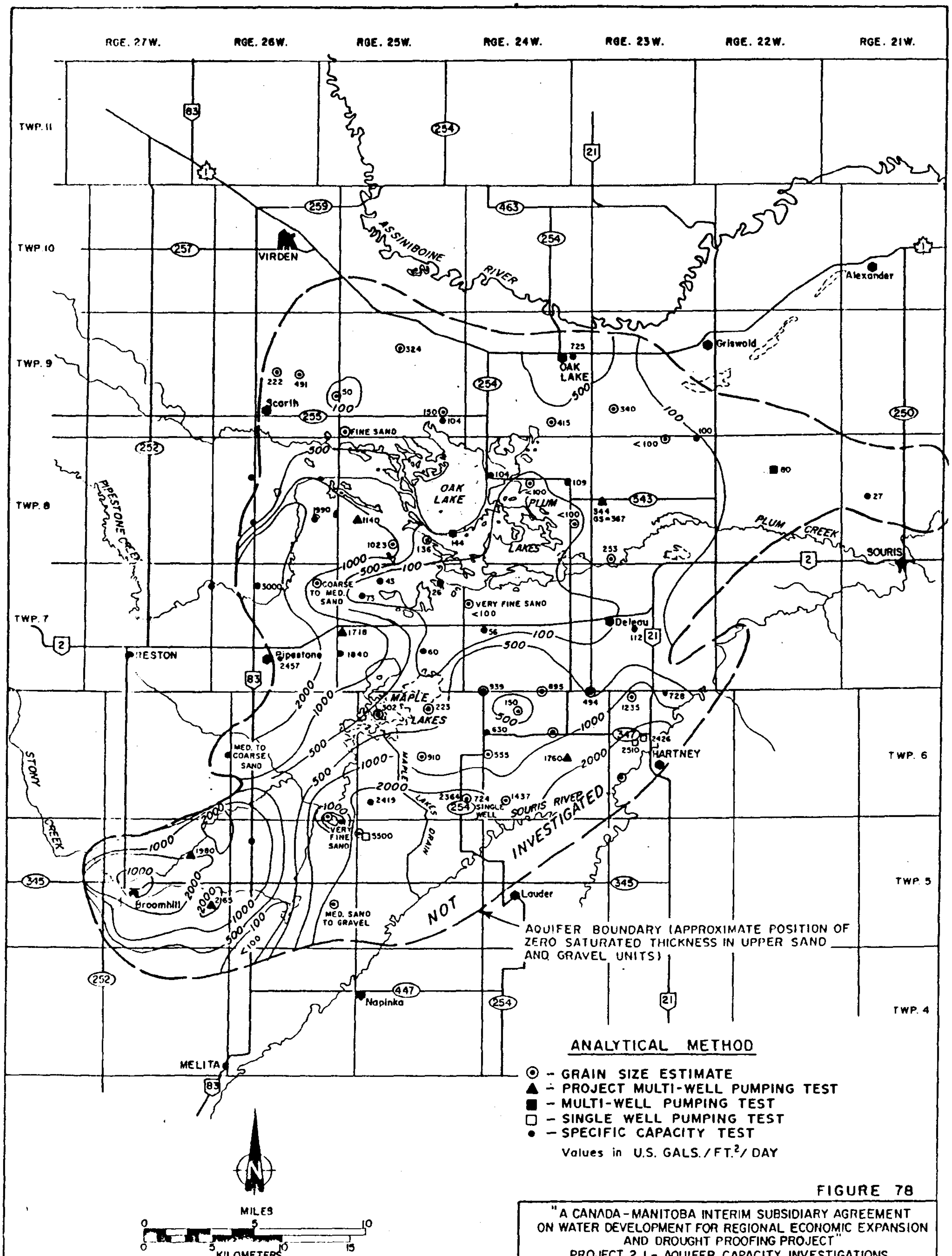
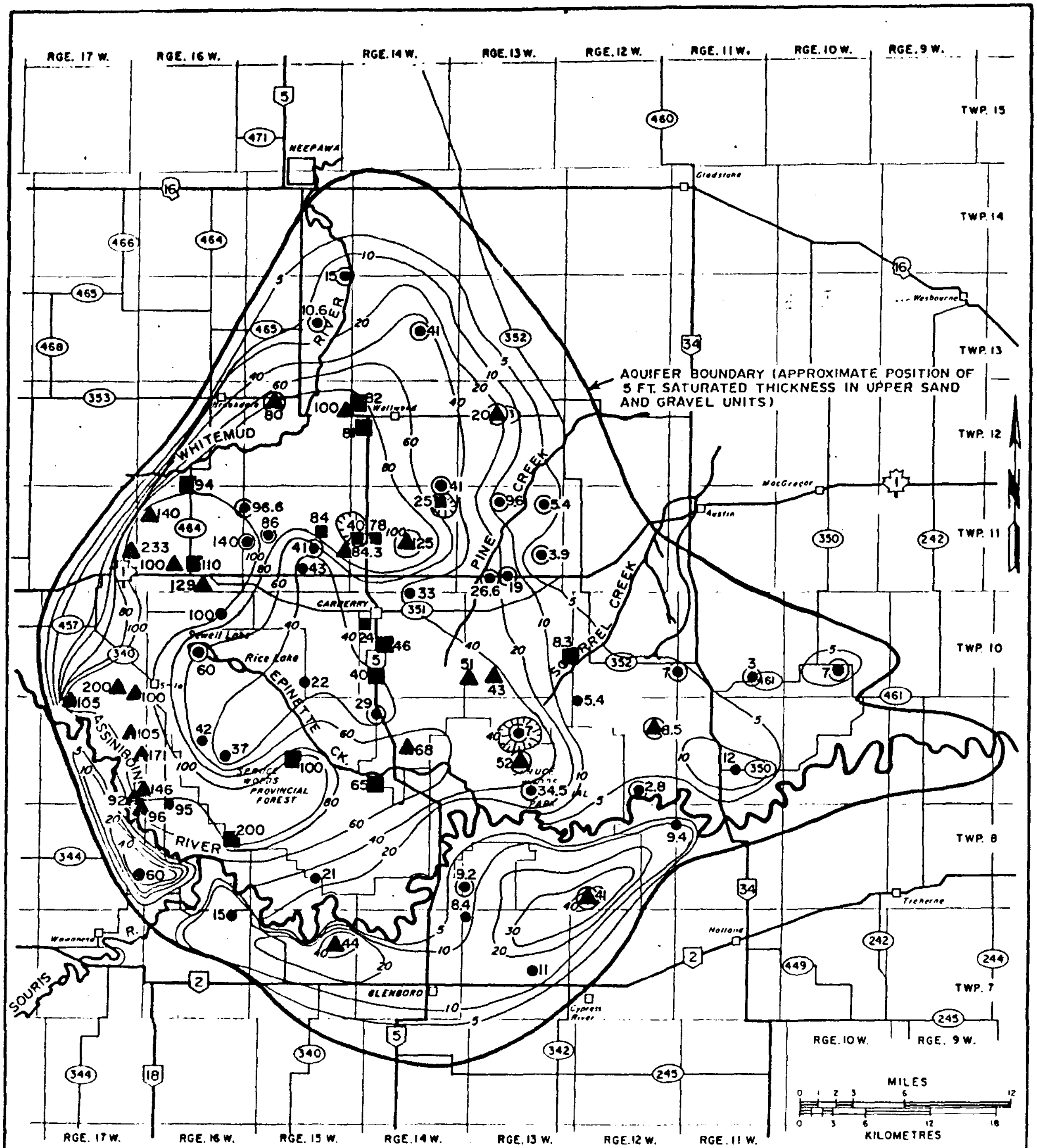


FIGURE 78

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

DRAWN F.B.R.	PROVINCE OF MANITOBA DEPARTMENT OF NATURAL RESOURCES WATER RESOURCES BRANCH	OAK LAKE AQUIFER HYDRAULIC CONDUCTIVITY
CHECKED		
PREPARED F.W. Render	SUBMITTED [signature] / APPROVED [signature]	SCALE AS SHOWN / DATE 86 06 27 / SHEET 78 OF 88 / FILE No 90-1-7-1141



ANALYTICAL METHOD

- FORMAL MULTIWELL PUMPING TEST
- MULTIWELL PUMPING TEST
- SINGLE WELL PUMPING TEST
- SPECIFIC CAPACITY
- GRAIN SIZE

—20— TRANSMISSIVITY X 10^3 U.S. GALS/FT./DAY

FIGURE 79

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 – AQUIFER CAPACITY INVESTIGATIONS

DRAWN F. B. R.	Manitoba Natural Resources Water Resources	ASSINIBOINE DELTA AQUIFER
CHECKED		**TRANSMISSIVITY**
PREPARED F. Render	SUBMITTED [signature] / APPROVED [signature]	SCALE AS SHOWN / DATE 86 06 27 / SHEET 79 OF 88 / FILE NO. 90-1-7-1141

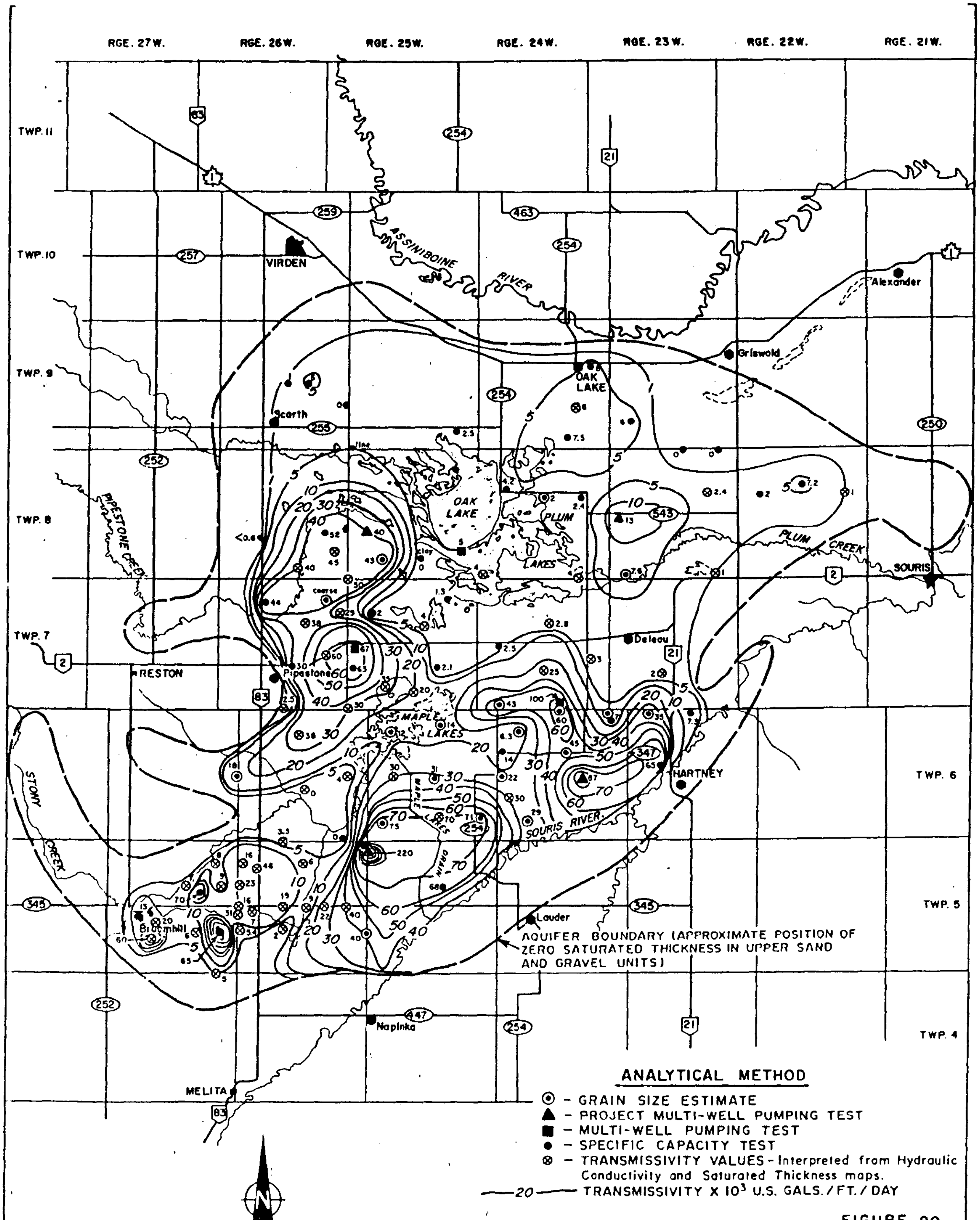


FIGURE 80

"A CANADA - MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

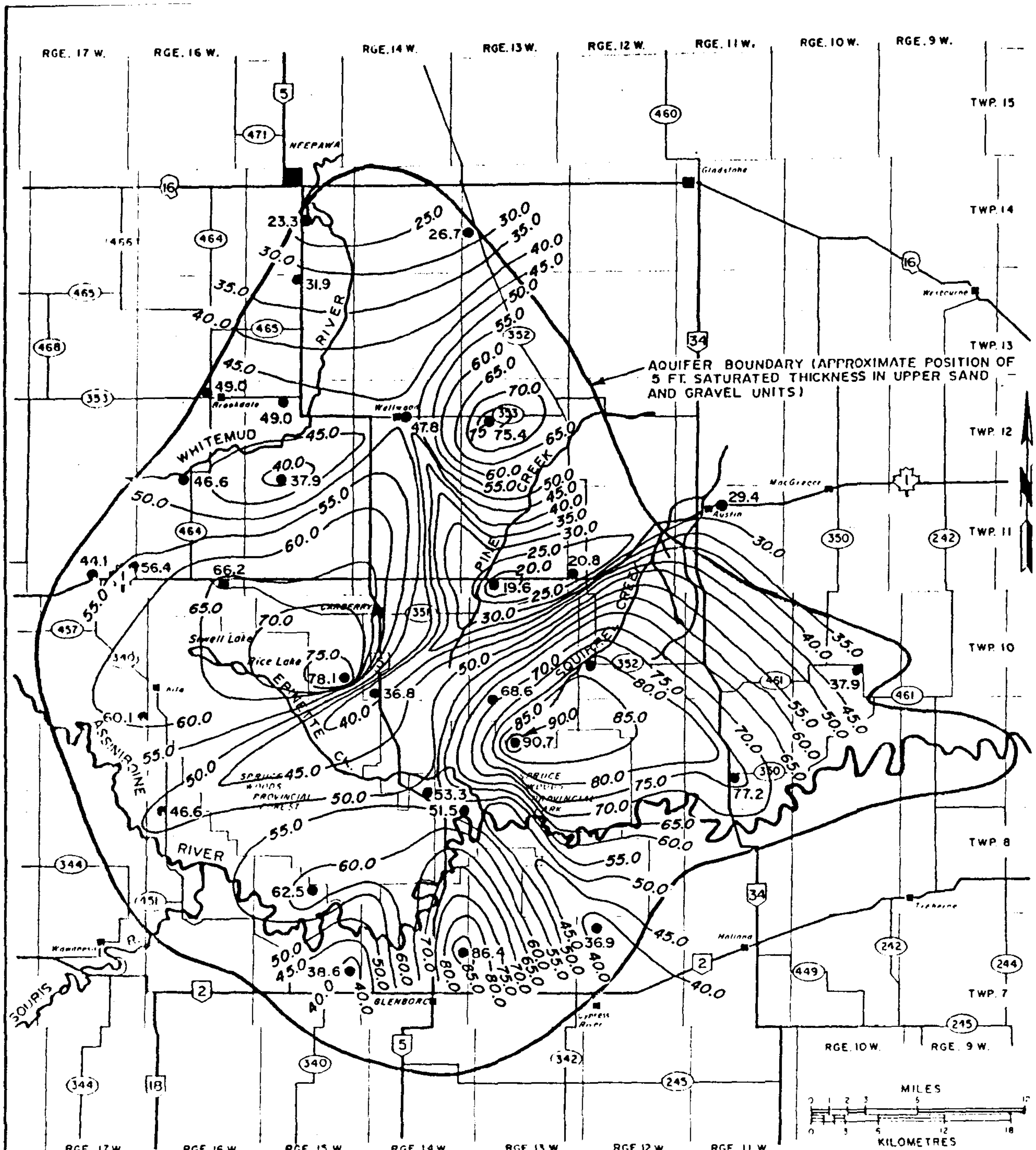
OAK LAKE AQUIFER

TRANSMISSIVITY

PROVINCE OF MANITOBA
DEPARTMENT OF NATURAL RESOURCES
WATER RESOURCES BRANCH

DRAWN	CHECKED	PREPARED	SUBMITTED	APPROVED
F.B.R.		F.W. Render	[signature]	[signature]

SCALE	DATE	SHEET	FILE No.
AS SHOWN	86 06 27	80 OF 88	90-1-7-1141



LEGEND

—50.0— CONTOURS OF EQUAL WATER CONTENT IN MILLIMETRES.

FIGURE 81

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

DRAWN	F.B.R.
CHECKED	
PREPARED	F. W. Render

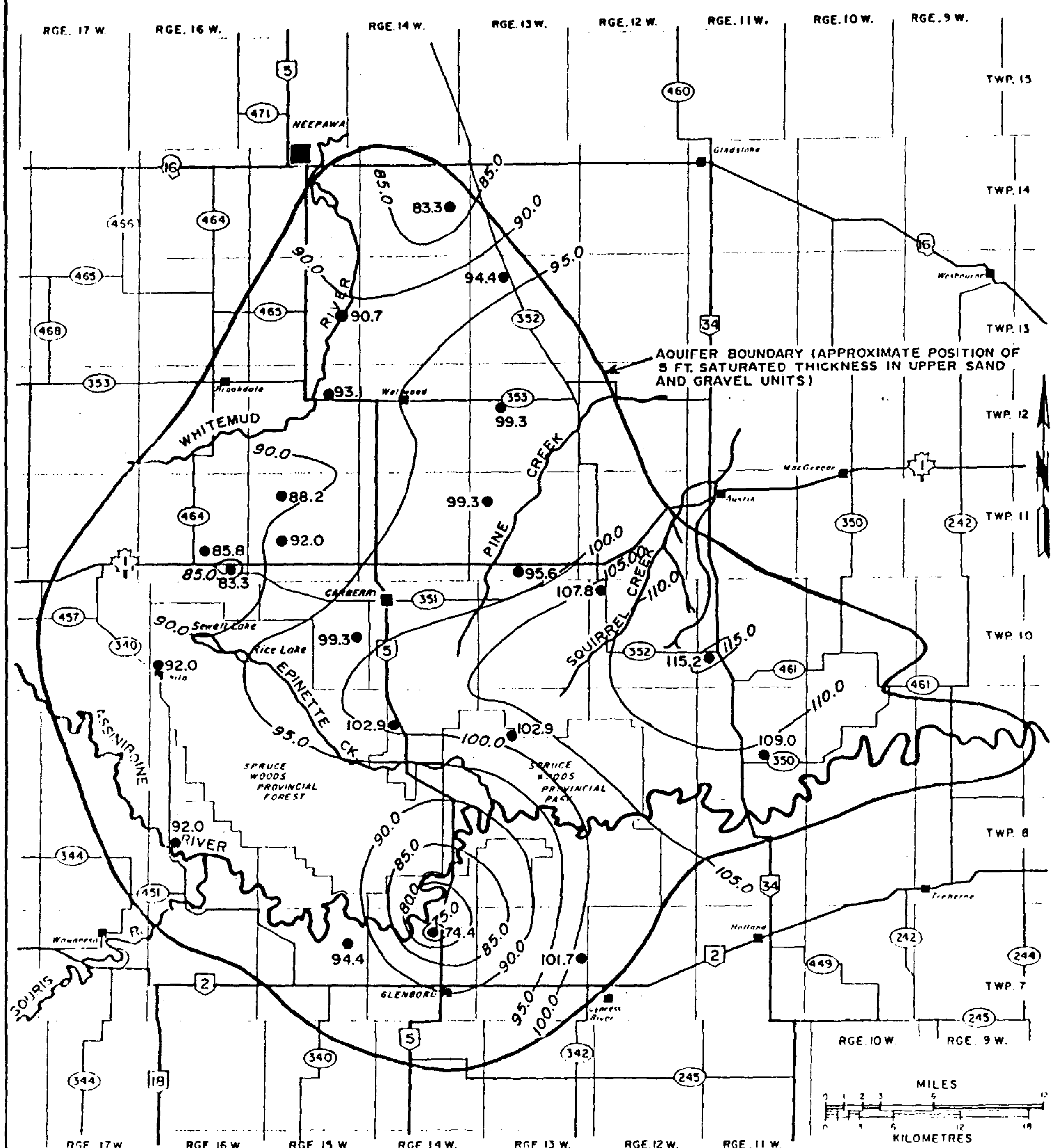
Manitoba Natural Resources
Water Resources

SUBMITTED / APPROVED

ASSINIBOINE DELTA AQUIFER

1986 SNOW SURVEY WATER CONTENT MAP

SCALE	DATE	SHEET	FILE NO.
AS SHOWN	86 06 27	81 OF 88	90-1-7-1141



LEGEND

—100.0— CONTOURS OF EQUAL WATER CONTENT IN MILLIMETRES.

FIGURE 82

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

ASSINIBOINE DELTA AQUIFER

1986 WOODED AREA SNOW SURVEY
WATER CONTENT MAP

Manitoba Natural Resources
Water Resources

DRAWN F.B.R.	CHECKED	PREPARED F.W. Render	SUBMITTED	APPROVED
SCALE AS SHOWN	DATE 86 06 27	SHEET 82 OF 88	FILE NO. 90-1-7-1141	

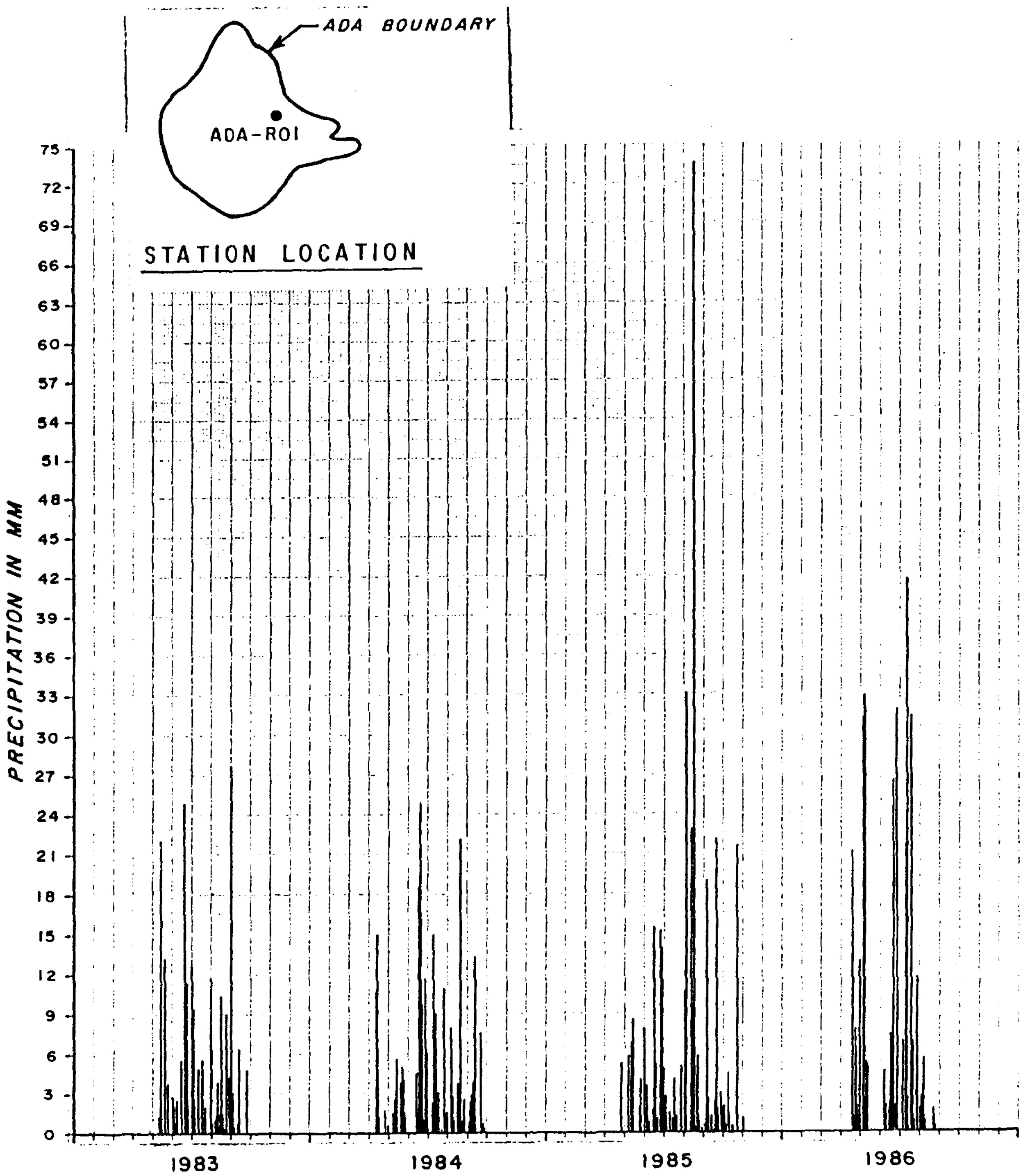


FIGURE 83

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

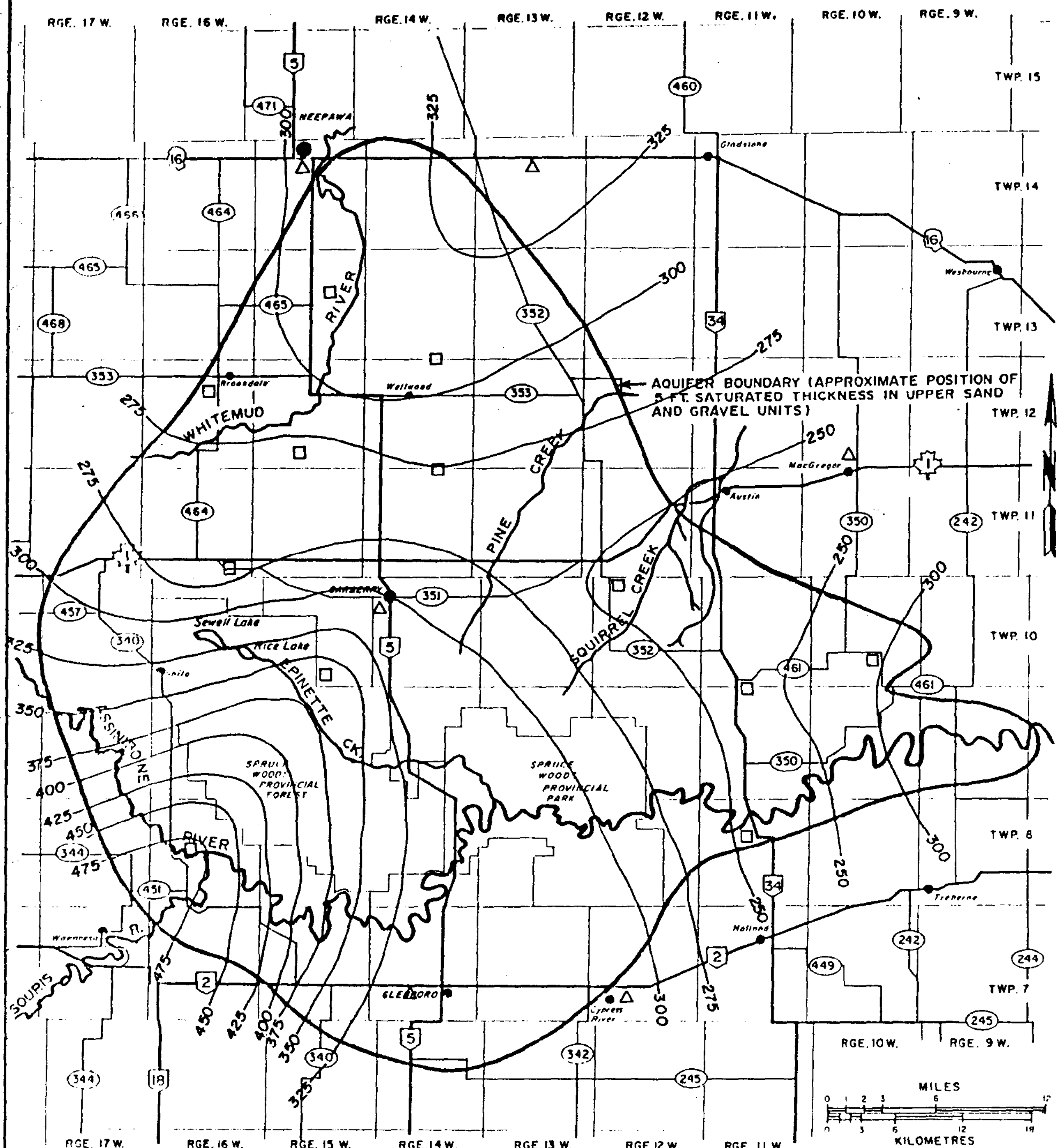
ASSINIBOINE DELTA AQUIFER

STATION ADA-ROI

RAINFALL HISTOGRAM

Manitoba Natural Resources
Water Resources

DRAWN	CHECKED	PREPARED	SUBMITTED	APPROVED	SCALE	DATE	SHEET	FILE NO.
F.B.R.		F.W. Render			AS SHOWN	86 06 27	83 OF 86	90-1-7-1141



LEGEND

—325— CONTOURS OF EQUAL RAINFALL IN MILLIMETRES.

□ W.R.B. DAILY RAIN GAUGE STATION

△ A.E.S. DAILY RAIN GAUGE STATION

FIGURE 84

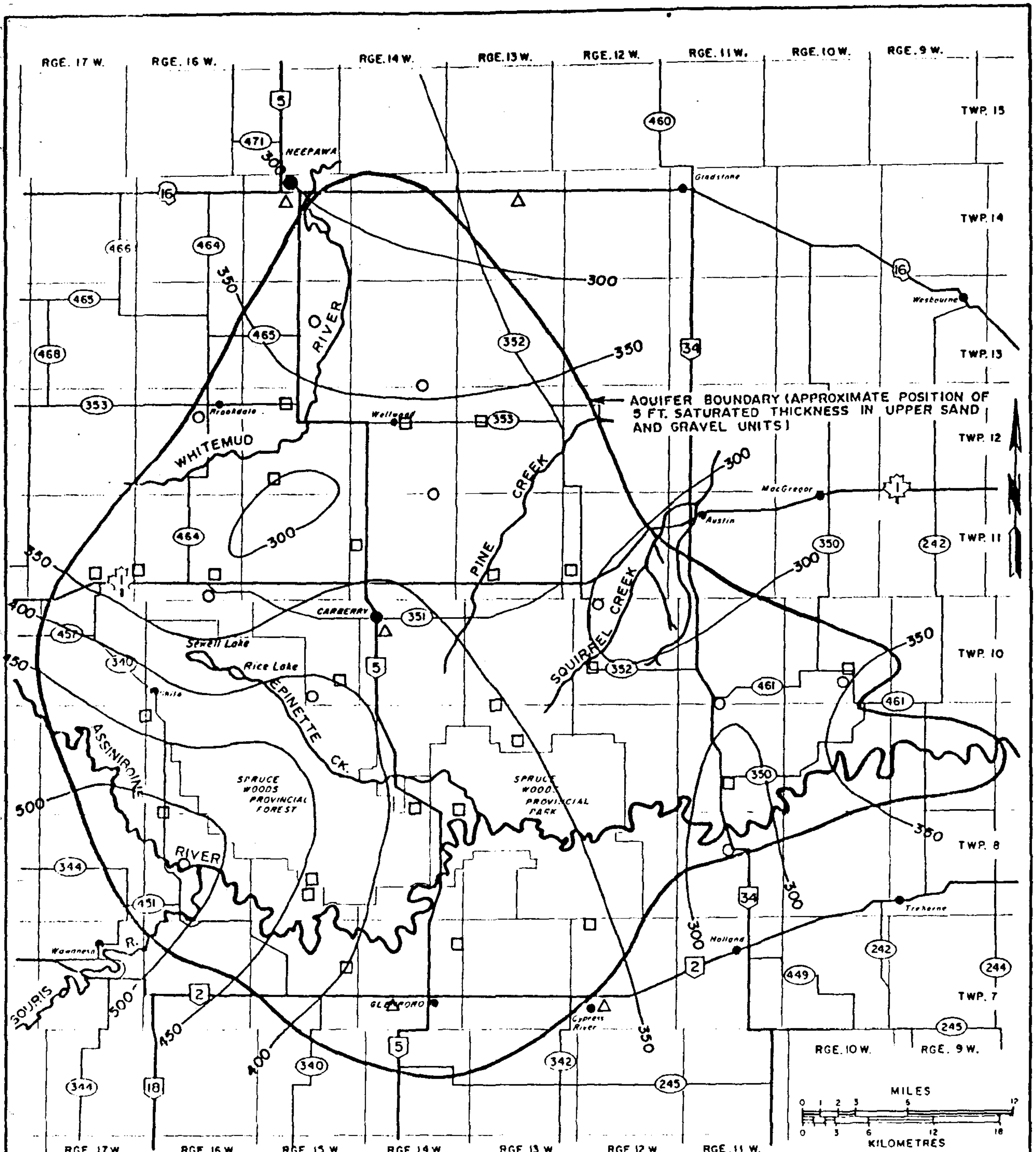
"A CANADA–MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 – AQUIFER CAPACITY INVESTIGATIONS

Manitoba Natural Resources
Water Resources

ASSINIBOINE DELTA AQUIFER

1983 RAINFALL

DRAWN	CHECKED	PREPARED	SUBMITTED	APPROVED	SCALE	DATE	SHEET	FILE NO.
F.B.R.		F.W. Render	[signature]	[signature]	AS SHOWN	86 06 27	84 OF 88	90-1-7-1141



LEGEND

—300— CONTOURS OF RAIN & SNOW WATER ACCUMULATION IN MILLIMETRES.

○ W.R.B. DAILY RAIN GAUGE STATION

△ A.E.S. DAILY RAIN GAUGE STATION

□ W.R.B. SNOW SURVEY STATION

FIGURE 85

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

DRAWN F.B.R.	Manitoba Natural Resources Water Resources	ASSINIBOINE DELTA AQUIFER
CHECKED		1983 RAIN & SNOW WATER
PREPARED F.W. Render	SUBMITTED [signature] APPROVED [signature]	SCALE AS SHOWN / DATE 86 06 27 / SHEET 85 OF 88 / FILE NO. 90-1-7-1141

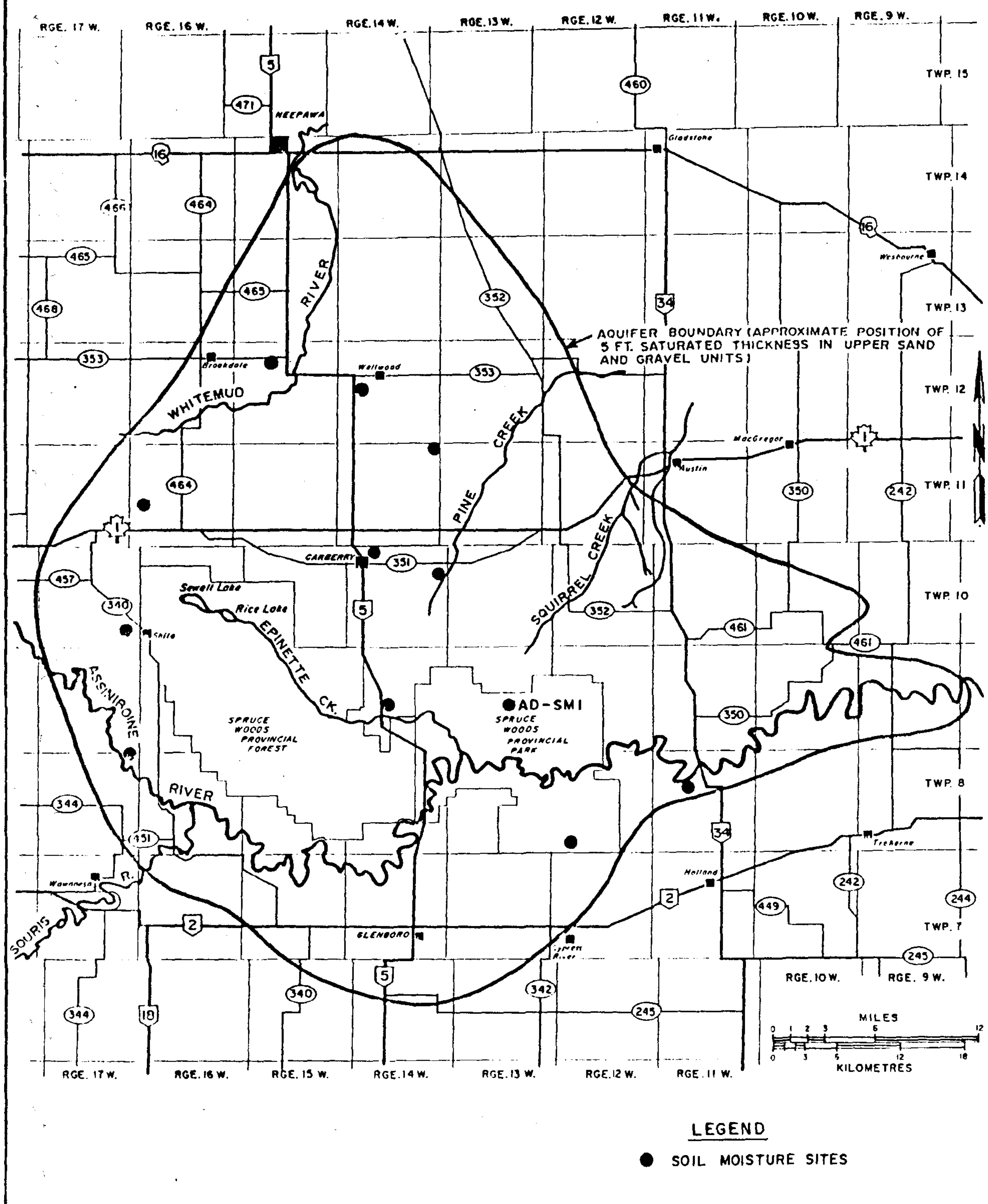


FIGURE 86

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

ASSINIBOINE DELTA AQUIFER

SURFICIAL SOIL MOISTURE STATIONS

Manitoba Natural Resources
Water Resources

DRAWN F.B.R.	CHECKED	PREPARED F.W. Render	SUBMITTED
APPROVED	SCALE AS SHOWN	DATE 86 06 27	SHEET 86 OF 88
FILE NO. 90-1-7-1141			

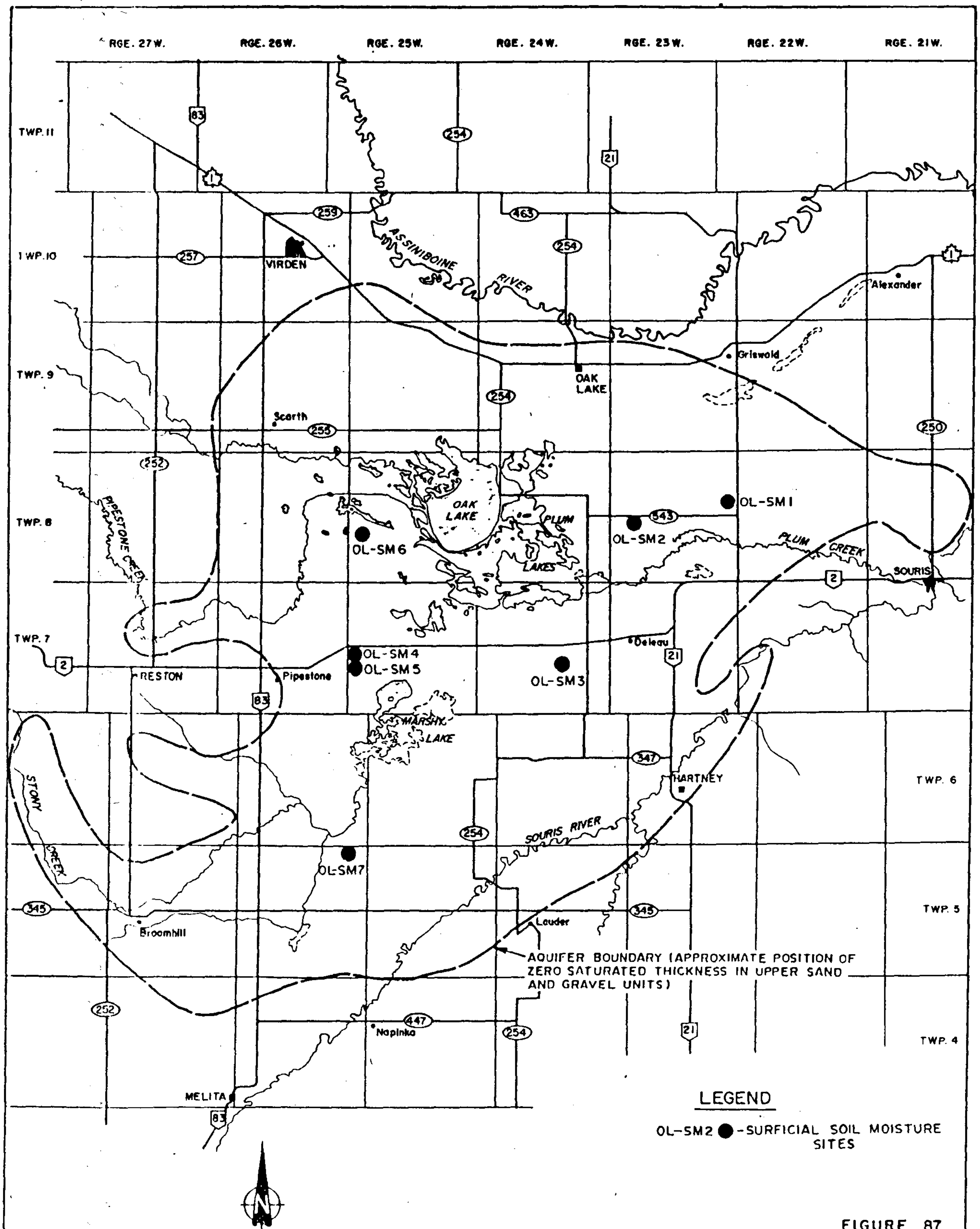


FIGURE 87

"A CANADA - MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"
PROJECT 2.1 - AQUIFER CAPACITY INVESTIGATIONS

DRAWN	PROVINCE OF MANITOBA DEPARTMENT OF NATURAL RESOURCES WATER RESOURCES BRANCH	OAK LAKE AQUIFER **SURFICIAL SOIL MOISTURE STATIONS**
CHECKED		
PREPARED F.W. Render	SUBMITTED [signature] / APPROVED [signature]	SCALE: AS SHOWN / DATE: 86 06 27 / SHEET: 87 OF 88 / FILE No: 90-1-7-1141

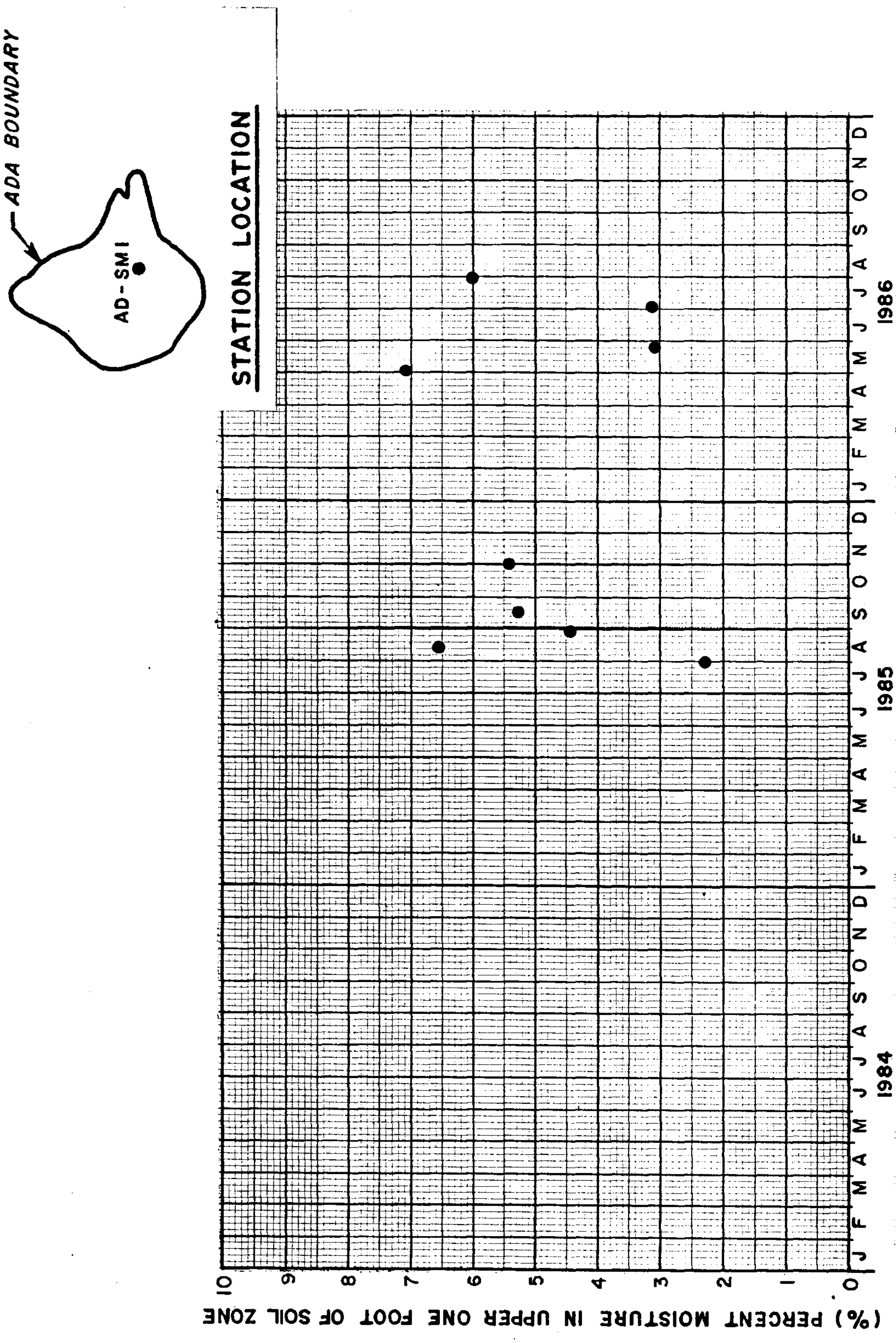


FIGURE 88

"A CANADA-MANITOBA INTERIM SUBSIDIARY AGREEMENT ON WATER DEVELOPMENT FOR REGIONAL ECONOMIC EXPANSION AND DROUGHT PROOFING PROJECT"

PROJECT 2.1 AQUIFER CAPACITY INVESTIGATIONS

ASSINIBOINE DELTA AQUIFER

SOIL MOISTURE HYDROGRAPH FOR STATION AD-SM1

DRAWN C.E.W.	Manitoba Natural Resources Water Resources		
CHECKED			
PREPARED F.W. Render	SUBMITTED	APPROVED	
SCALE AS SHOWN	DATE 860627	SHEET 88 OF 88	FILE NO. 90-1-7-1141

TABLE 1

SUMMARY OF WELLS AND TEST HOLES DRILLED
ASSINIBOINE DELTA AQUIFER

NUMBER	WELL DEPTH (FEET)	TEST HOLE DEPTH (FEET)	REMARKS
AA1	12.85	35	
1	67.32	120	
2	52	60	
2A	21.32	22	
3	84	95	
4	108.65	114.5	
4A		177.12	
5		75	
5A	87.3	110	
6	25	79.5	
6A	92.0	105	
7	117	145	
7A	69.0	69.5	
7B		177.12	
8		134	
8A	58.45	85	
9	18.3	40	
10	55.2	63.5	
11.0	89.9	120.0	
11 A.	40.7	40.7	

12	35.4	105
13		
14	100	120
15	88.02	117
16	73	78
17	87.8	104
18	54.3	95
18A	30.1	31.5
19A	97.3	118
19	39.9	40
20	79.5	125
21	42.2	75
22	92.4	130
23	63	107
24	72.2	105
25	64	76
26		
27	35.5	49
28	30.5	40
29	77	100
30	75.9	89
31	31	45
32	79	100
33	67.75	93
34A	44.86	45
34	77.3	100
35B	33.0	34
35A	58.5	82.5
35		100.00

36	62.76	95
37	59.9	115
38A	55.24	80
38		70
39	66	120
40	54.9	120
41	37.42	101
42	100	110.0
42B	43.3	45.59
42A		75.0
42C		230.75
44		100
45	33.9	50
46	31.42	60
47A	73	80
47	83	86
48	80	65
49	72	81
50	46	51
50A	42.6	45
51	61.9	73
52	72.8	81
52A	72.8	78
53	63.4	72
54	62.43	67
54A	58.86	62.5
55	72.7	80
56	74.56	84
56A	74.04	82

57	72.5	77
57A	72.2	80
58	84.5	100
58A	85.48	104
59A	81	85
59		85.7
60	112.7	130.00
60A	113.47	120
61	103.63	120
62A		49
62	12.79	59.04
63		75
64	83.57	123
65	69.7	75.4
65A	26.24	27
66	40.67	54.12
67	57.07	63.63
68	119.72	122.97
68R		
69		135.63
70	4.7	88.56
71	17.38	88.56
72	21	21.32
73	31.26	153.5
74	40.7	40.7
75	34.37	34.37
76	32.8	32.8
77	40.93	83.64
78	33.42	34.44

79	32.7	67.24
79R		137.76
80		118.08
81		108.24
81A	89	
82		98.42
83		109.91
84		68.9
85		123.03
86		73.82
87		78.74
88		98.43
89		108.27
90	60.82	68.90
90A	68.90	78.74
91	95.64	101.71
91A	88.25	93.50
92		124.64
93		236.16
94		78.72
95		118.08
96		140.09
97		140.09
98		170.60
99		200.13
100		200.13
101	59.7	79.5
102		128
103		60.68

OLA-1A	29.70	56.00	
OLA-2	35.00	42.00	
OLA_3		35.00	
OLA-3M	19.00	21.00	
OLA-4	32.00	36.00	
OLA-5A	60.30	65.00	
OLA-5B	34.50	35.00	
OLA-6	27.00	52.00	
OLA-7	53.60	59.00	
OLA-7B	20.90	21.00	
OLA-8A	62.00	67.50	
OLA-8B	30.20	31.50	
OLA-9	36.30	40.00	
OLA-10		40.00	DRY HOLE
OLA-11	14.40	35.00	
OLA-12	16.50	30.00	
OLA-14	40.50	48.00	
OLA-15	29.50	40.00	
OLA-16	31.90	33.50	
OLA-17			
OLA-18		30.00	DRY HOLE
OLA-18M		25.00	
OLA-20	39.30	50.00	
OLA-21	34.22	90.00	
OLA-22	37.75	60.00	
OLA-23	29.40	89.50	
C-24 TH		44.62	
C-25 TH		55.77	
C-26 TH		59.05	

C-27	82.02
OLA-28 TH	51.84
C-29 TH	60.69
C-30 TH	34.45
C-31 TH	43.30
C-32	88.58
C-33	37.73
C-34	52.49
C-35	60.69
C-36	91.86
C-37	73.83
C-38	73.82
C-40	49.21
C-41	39.37
C-42	59.05
C-43	98.42
C-44	83.66
C-46	24.61
C-47	14.76
C-48	29.53
C-49	59.05
C-50	39.37
C-51	39.37
C-52	29.53
C-53	42.65
C-54	65.62
C-55	59.05
C-56	34.49
C-57	29.53

C-58		29.53
OLA-59A	35.43	78.74
OLA-59		27.88
GLENORA 3	37.98	60.00
GLENORA 4	18.37	40.00
C-5	29.86	41.83
C-6	34.68	56.43
C-7	41.99	52.49
MA-2	44.69	75.00
WA-81-1	80.01	90.00
WA-81-1A	34.46	35.00
WA-81-2	108.86	140.00
WA-81-3	121.11	138.00
WA-81-4	114.4	117.50
WA-81-5	118.07	122.70
ELIE 81-1		68.70
ELIE 81-2		50.00
ELIE 81-3		50.00
ELIE 81-4	47.82	62.50
ELIE 81-5		61.00
ELIE 81-6		52.00
ELIE 81-7	71.67	86.00
ELIE 81-8		63.90
ELIE 81-9		45.00
ELIE 81-10		61.50
ELIE 81-11	49.57	53.10
ELIE 81-12		65.00

TABLE II

PUMPING TEST CONTRACTS

FISCAL YEAR	CONTRACTOR	DRILLING	PUMPING TEST
1983 - 1984	Watkins and Argue	$35,621.50	
	Caprock Drilling		$34,130.00
1984 - 1985	Ralph Edwards and Sons	$15,360.75	
	Watkins and Argue	$ 9,280.00	
	Friesen Drillers		$29,092.50
1985 - 1986	Watkins and Argue	$27,443.00	
	Maple Leaf Enterprises		$33,632.50

TABLE III

EXPENDITURES

FISCAL YEAR	SUPPLIES	CONTRACTS
1985 - 1986	$ 51,100	$ 61,000
1985 - 1986	35,400	53,600
1983 - 1984	40,800	70,300
1982 - 1983	112,000	2,800
1981 - 1982	64,300	8,500
1980 - 1981	$155,000	$ 6,600
TOTAL	$459,000	$203,000

TABLE IV

GROUNDWATER CHEMISTRY

WELL NAME	ANAL. NO.	DA MO YEAR	TIME	EC	PH	CA	MG	NA	K	FE	HCO3	CO3	OH	SO4	CL	NO3	DS	TH	M ALK
ADA1	03804	11051981		470	7.80	70.	20.	10.	2.0	1.9	310.	0.0	0.0	20.	2.	.01	374.	257.	254.
ADA10	20837	06111980		636.	7.4	98.	25.	10.	2.6	0.62	422.	0.0	0.0	20.	2.	0.01	420.	348.	346.
ADA11	21603	09121980		490.	7.5	73.	18.	10.	2.	10.2	337.	0.0	0.0	5.	2.	0.01	300.	257.	276.
ADA11A	04841	01041981		416.	7.7	68.	13.	10.	2.	0.2	261.	0.0	0.0	17.	2.	0.1	278.	224.	214.
ADA12	05515	24041981		450	7.40	83.	13.	10.	2.	10.	310.	0.0	0.0	10.	2.	.01	298.	261.	254.
ADA14	05892	25031981		513.	7.20	75.	23.	10.	3.1	0.32	349.	0.0	0.0	12	2.	.01	340.	282.	286.
ADA15	04842	01041981		417.	7.6	65.	14.	10.	2.6	0.33	278.	0.0	0.0	6.	2.	0.02	198.	221.	228.
ADA16	20838	13111980		410.	7.6	60.	18.	10.	2.	0.32	207.	0.0	0.0	50.	2.	0.55	290.	224.	170.
ADA17	21604	02121980		566.	7.5	95.	15.	10.	2.	0.01	388.	0.0	0.0	5.	2.	0.01	350.	299.	318.
ADA18	20998	26111980		564.	7.4	95.	12.	10.	3.3	0.81	390.	0.0	0.0	22.	2.	0.01	380.	287.	320.
ADA18A	20997	27111980		513.	7.6	108.	12.	10.	2.	0.08	378.	0.0	0.0	5.	2.	0.01	340.	319.	310.
ADA19A	21605	16121980		482.	7.6	88.	8.	10.	2.	2.3	327.	0.0	0.0	5.	2.	0.01	320.	253.	268.
ADA19A	22845	16091985		322.	7.70	38.6	12.1	2.2	5.00	18.7	212.	0.0	0.0	15.0	2.0	0.04	200.	146.	174.
ADA2	04120	01041981		780.	7.40	116.	39.	20.	9.3	12.8	356.	0.0	0.0	172	6.	.01	620.	450	292.
ADA20	20999	25111980		424.	7.6	83.	10.	10.	2.4	0.08	303.	0.0	0.0	7.	2.	0.01	290.	249.	248.
ADA22	04121	01041981		488.	7.50	87.	19.	10.	3.9	0.40	349.	0.0	0.0	10	2.	.01	390.	296.	286.
ADA23	07533	21051981		550	7.45	83.	20.	10.	3.0	.77	361.	0.0	0.0	6.0	2.	.01	339.	320.	296.
ADA24	20839	19101980		540.	7.5	90.	18.	10.	2.4	1.57	373.	0.0	0.0	5.	2.	0.01	350.	299.	306.
ADA25	20840	19101980		410.	7.5	60.	15.	10.	2.	0.27	268.	0.0	0.0	5.	2.	0.01	270.	212.	220.
ADA27	20841	24111980		382.	7.70	60.	13.	10.	2.	0.09	244.	0.0	0.0	7.0	2.	.01	240.	204.	200.
ADA29	21529	29091983		513.	7.25	79.4	18.1	7.36	5.00	8.30	337.	0.0	0.0	10.2	2.	0.01	320.	273.	276.
ADA29	21530	29091983		525.	7.25	80.6	18.7	9.15	5.00	7.76	342.	0.0	0.0	10.7	2.	0.01	320.	278.	280.
ADA29	21771	03101983		510.	7.25	80.0	18.1	6.86	5.00	7.27	332.	0.0	0.0	9.9	2.	0.01	330.	274.	272.
ADA29	21871	04101983		505.	7.25	81.5	18.5	6.87	5.30	7.30	332.	0.0	0.0	9.1	2.	0.01	320.	280.	272.
ADA29	21872	04101983		503.	7.25	78.0	17.7	6.56	5.00	7.06	332.	0.0	0.0	8.4	2.	0.01	320.	268.	272.
ADA3	04838	01041981		569.	7.6	73.	26.	18.	4.2	3.35	259.	0.0	0.0	98.	8.	0.02	399.	290.	212.
ADA30	06805	11051981		560	7.40	93.	18.	10.	2.3	18.	378.	0.0	0.0	5.	3.	.02	374.	307.	326.
ADA30	22838	16091985		460.	7.40	69.0	18.0	2.7	5.00	15.7	317.	0.0	0.0	15.	2.0	0.04	300.	247.	260.
ADA34	08822	04061981		590.	7.40	100.	25.	10.	3.8	2.2	389	0.0	0.0	15.	5.	.01	360.	353.	319
ADA34	22393	12101983		492.	7.55	74.4	19.6	2.56	7.50	0.60	317.	0.0	0.0	12.	3.	0.01	280.	266.	260.
ADA34	22664	17101983		475.	7.45	77.4	20.9	2.70	5.00	0.82	310.	0.0	0.0	14.	2.5	0.03	280.	280.	254.
ADA34	22665	17101983		474.	7.50	75.5	19.6	2.60	5.00	0.92	315.	0.0	0.0	8.4	2.5	0.11	290.	270.	258.
ADA34	22666	17101983		470.	7.40	75.5	19.5	2.65	5.00	0.07	300.	0.0	0.0	8.4	2.5	0.13	290.	269.	246.
ADA34A	20944	13101981		410.	8.05	70.	15.	10.	2.0	0.04	268.	0.0	0.0	15.	2.	.01	220.	237.	220.
ADA37	03893	10031981		576.	7.60	80.	29.	10.	3.7	1.28	386.	0.0	0.0	25	5.	.01	380.	319	316.
ADA39	06806	11051981		520.	7.60	73.	28.	10.	2.0	1.7	364.	0.0	0.0	10.	2.	.20	347.	298.	298.
ADA4	03894	25031981		491.	7.40	78.	19.	10.	3.7	0.81	332.	0.0	0.0	18	2.	.01	310.	273.	272.
ADA40	07192	15051981		880.	7.20	128.	38.	10.	5.2	3.5	488.	0.0	0.0	118	2.	.01	630.	476.	400.
ADA40	22836	16091985		310.	8.40	26.4	24.9	2.4	5.00	17.7	207.	2.40	0.0	12.0	2.0	0.01	200.	169.	174.
ADA42	21135	26091983		610.	7.40	94.4	29.2	5.20	5.00	7.15	420.	0.0	0.0	6.2	2.	0.01	390.	356.	344.
ADA42	21136	26091983		600.	7.30	92.6	28.3	5.30	5.00	6.34	405.	0.0	0.0	5.6	2.	0.01	360.	348.	332.
ADA42	21531	29091983		635.	7.40	95.6	29.8	5.31	5.00	6.56	422.	0.0	0.0	5.5	2.	0.01	390.	362.	346.
ADA5A	04839	01041981		516.	7.6	70.	26.	10.	3.2	0.79	349.	0.0	0.0	13.	2.	0.13	320.	282.	286.
ADA51	15362	09081984		488.	7.4	70.7	16.4	3.1	5.	0.65	268.	0.0	0.0	80.	7.	1.6	350.	245.	220.
ADA51	17555	04071985		727.	7.6	75.6	18.4	3.63	5.	0.73	227.	0.0	0.0	35.	8.	2.2		265.	186.
ADA52	03628	20021985		401.	7.7	58.	21.7	4.11	5.	36.	210.	0.0	0.0	65.	3.	0.02	270.	234.	172.
ADA52A	03629	20021985		443.	7.65	63.7	23.	4.78	5.	0.05	249.	0.0	0.0	60.	3.	0.02	250.	254.	204.
ADA53	15365	07081984		435.	7.6	57.9	15.	1.75	5.	0.24	220.	0.0	0.0	40.	5.	1.9	300.	207.	180.
ADA56	15216	27061982		530.	7.1	70.6	25.	8.08	5.	2.98	246.	0.0	0.0	75.	4.	0.04	330.	280.	202.
ADA55	15363	07081984		[illegible]	7.45	65.	24.3	7.24	5.	2.73	239.	0.0	0.0	82.	4.	0.19	380.	263.	196.
ADA56	19265	25071985		501.	7.3	69.	26.8	10.	5.0	2.75	259.	0.0	0.0	83.	5.0	0.01		283.	212.
ADA57	17709	05071985		569.	7.0	67.1	26.4	9.97	5.0	2.23	244.	0.0	0.0	90.	7.0	0.26		276.	200.
ADA57	19264	25071985		597.	7.7	72.6	28.7	11.3	5.0	2.13	249.	0.0	0.0	90.	8.0	1.2		300.	204.
ADA57P	15215	05071982		541.	7.60	69.9	25.7	10.7	5.00	2.05	239.	0.0	0.0	85.	4.	.36	360.	281.	196.
ADA58	15364	10031984		515.	7.30	79.5	16.9	3.30	5.00	5.90	329.	0.0	0.0	13.	2.0	0.03	350.	267.	270.
ADA58	17556	05071985		527.	7.3	80.2	18.3	3.52	5.	5.31	337.	0.0	0.0	8.5	2.	0.01		275.	276.
ADA58P	17710	05071985		524.	7.25	80.	17.9	3.3	5.0	5.48	337.	0.0	0.0	8.0	2.0	0.01		274.	276.
ADA59P	15217	05071982		432.	7.55	63.8	16.4	2.89	5.00	0.57	251.	0.0	0.0	28.	2.	1.3	270.	236.	206.
ADA6A	21602	03121980		627.	7.4	103.	20.	10.	3.2	0.76	432.	0.0	0.0	20.	2.	0.01	400.	340.	354.
ADA6A	22842	16091985		283.	8.15	23.6	21.0	6.1	5.00	12.2	173.	0.0	0.0	14.	2.0	0.01	190.	145.	158.
ADA60	19266	25071985		535.	8.2	66.3	27.1	5.0	5.0	0.45	310.	0.0	0.0	28.	2.0	2.0		277.	254.
ADA61	15361	09081984		473.	7.45	75.4	16.8	4.8	5.	1.92	288.	0.0	0.0	20.	2.	0.1	320.	258.	236.
ADA62	26667	22111985		535.	7.75	68.2	28.	15.2	5.	1.26	310.	0.0	0.0	28.	6.	.01	330.	286.	254.
ADA62	26667	22111985		535.	7.75	68.2	28.	15.2	5.	1.26	310.	0.0	0.0	28.	6.	.01	330.	286.	254.
ADA64	19495	09101984		539.	7.50	71.0	24.0	17.2	5.00	1.53	322.	0.0	0.0	32.	2.0	0.04	320.	277.	264.
ADA64	19496	09101984		535.	7.60	71.0	23.5	15.7	5.00	1.46	373.	0.0	0.0	32.	3.0	0.01	310.	275.	306.
ADA64	19506	09101984		544.	7.55	72.0	22.0	14.8	5.00	1.40	320.	0.0	0.0	27.	3.0	0.08	330.	270.	262.
ADA64	19507	09101984						14.5	5.00	1.40				25.	3.0	0.13		276.	
ADA7	08319	29051981		497.	7.65	75.	18.	10.	2.5	1.9	328.	0.0	0.0	15.	2.	.17	346.	262.	269.
ADA7A	03166	01041981		477.	7.6	68.	25.	10.	2.6	0.42	317.	0.0	0.0	10.	2.	0.01	418.	273.	260.
ADA8A	05514	24041981		470	7.50	78.	18.	10.	2.	.34	307.	0.0	0.0	20.0	2.	.02	281.	269.	252.
ADA9	04840	01041981		472.	7.8	63.	22.	10.	3.	0.03	259.	0.0	0.0	33.	7.	0.35	300.	249.	212.
OLA1	18652	14101980		480.	7.4	78.	23.	5.	3.2	0.34	322.	0.0	0.0	20.	2.	0.1	340.	290.	264.
OLA14	19518	08101980		651.	8.0	110.	35.	35.	6.2	1.5	332.	0.0	0.0	225.	4.	0.01	640.	419.	272.
OLA16	18932	09101980		403.	7.7	55.	18.	10.	2.2	0.07	212.	0.0	0.0	22.	2.	6.9	270.	212.	174.
OLA2	20832	29101980		963.	7.2	113.	53.	30.	5.2	13.8	437.	0.0	0.0	182.	7.	0.01	650.	501.	358.
OLA20	17582	02101980		520.	7.8	73.	20.	10.	2.2	3.04	337.	0.0	0.0	17.	2.5	0.01	330.	265.	276.
OLA21	20941	13101981		515.	7.95	85.	18.	10.	2.0	0.16	338.	0.0	0.0	7.2	2.	.05	290.	287.	277.
OLA22	20942	13101981		701.	7.90	86.	30.	28.	4.8	0.08	415	0.0	0.0	47.	6.	.10	430.	343.	340.
OLA23	20943	13101981		582.	7.70	78.	18.	10.	2.6	0.30	383.	0.0	0.0	4.2	2.	.05	340.	317.	314.
OLA3M	20833	04111980		1110.	7.5	103.	58.	60.	7.6	1.38	373.	0.0	0.0	265.	36.	0.01	600.	496.	306.
OLA3M	22832	16091985		607.	8.50	30.0	39.1	55.3	6.00	122.	273.	4.80	0.0	190.	25.	0.01	370.	236.	232.
OLA36	04317	05031984		571.	8.	74.7	33.5	5.46	5.	2.03	349.	0.0	0.0	34.	3.	0.01	370.	324.	286.
OLA4	20834	30101980		482.	7.7	55.	29.	10.	2.4	0.06	273.	0.0	0.0	47.	2.	0.01	340.	257.	224.
OLA40	05414	19031984		784.	7.9	112.	37.2	11.4	5.	3.01	510.	0.0	0.0	18.	8.	0.01	460.	433.	418.
OLA5P	20342	18101984		406.	7.4	57.9	17.3	5.54	5.	0.56	244.	0.0	0.0	25.	2.	0.01	260.	224.	200.
OLA5P	20341	19101984		411.	7.55	59.3	20.1	5.07	5.	0.5	242.	0.0	0.0	25.	2.	0.02	270.	231.	198.
OLA5P	20340	20101984		432.	7.45	61.3	21.	4.54	5.	0.51	246.	0.0	0.0	40.	2.	0.24	280.	239.	202.
OLA5P	20339	21101984		450.	7.55	63.3	21.7	4.44	5.	0.5	239.	0.0	0.0	40.	2.	0.33	290.	247.	196.
OLA5	19519	22101980		389.	7.5	58.	18.	10.	2.3	0.33	254.	0.0	0.0	7.	2.	0.01	250.	219.	208.
OLA59P	24663	16101985		1360.	7.25	132.	70.8	86.0	7.50	6.88	422.	0.0	0.0	425.	11.	0.01	1010.	621.	346.
OLA59P	24664	17101985		1250.	7.25	120.	66.5	79.7	7.50	5.63	412.	0.0	0.0	350.	11.	0.01	950.	574.	338.
OLA59P	24665	18101985		1240.	7.25	119.	66.5	79.3	8.00	5.72	403.	0.0	0.0	360.	11.	0.26	920.	572.	330.
OLA59P	24666	19101985		1230.	7.30	117.	65.7	78.4	8.00	5.57	405.	0.0	0.0	360.	11.	0.37	910.	564.	332.
OLA59P	24927	20101985		1200.	7.35	110.	59.4	66.4	7.50	5.04	378.	0.0	0.0	330.	11.	0.41	810.	518.	326.
OLA6	19521	21101980		567.	7.5	83.	28.	10.	3.2	1.73	349.	0.0	0.0	22.	8.	0.01	350.	323.	286.
OLA62	15858	12061985		501.	7.95	65.6	21.4	5.22	5.00	1.26	276.	0.0	0.0	58.	2.0	0.01		252.	226.
OLA62	18165	15071985		547.	7.45	66.6	23.5	5.0	5.00	2.86	283.	0.0	0.0	55.	4.0	1.20		263.	232.
OLA62A	15859	12061985		488.	7.70	64.4	21.1	5.16	5.00	3.77	254.	0.0	0.0	58.	2.0	0.01	21.	248.	208.
OLA7A	19520	15101980		685.	7.4	103.	30.	10.	3.2	2.3	473.	0.0	0.0	7.	2.	0.01	420.	381.	388.
OLA7A	22833	16091985		368.	7.95	34.5	28.3	8.5	5.00	14.4	249.	0.0	0.0	12.0	2.0	0.01	230.	203.	204.
OLA8A	20835	27101980		822.	7.3	120.	43.	10.	3.8	6.	573.	0.0	0.0	20.	6.	0.04	530.	477.	470.
OLA8BP	19896	12101984		799.	7.25	114.	34.5	9.35		3.85	534.	0.0	0.0	18.	6.	0.01	510.	427.	438.
OLA8BP	19894	13101984		821.	7.2	114.	34.	9.5		3.76	539.	0.0	0.0	20.	5.	0.01	510.	425.	442.
OLA8BP	19895	14101984		799.	7.2	112.	34.	9.1		3.7	534.	0.0	0.0	18.	5.	0.23	520.	420.	438.
OLA8BP	19897	11111984		810.	7.35	114.	35.	9.75		3.93	542.	0.0	0.0	18.	6.	0.01	520.	429.	444.
OLA9	20836	03111980		1140.	7.2	150.	73.	30.	7.4	0.65	791.	0.0	0.0	25.	11.	0.01	720.	675.	648.
OLA9	22834	16091985		746.	8.30	20.2	70.6	35.1	8.00	5.40	493.	0.0	0.0	2.0	2.0	0.01	430.	341.	404.