REVIEW OF THE WATER SUPPLY CAPACITY OF THE WINKLER AQUIFER

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SUMMARY

The water supply capacity of the Winkler Aquifer system has been reviewed. The system has been defined into upper and lower units. The lower unit is poorly defined and its capacity has not been considered in this review. The upper unit consists of a elongated sand and gravel deposit that is 17 miles long, has thicknesses up to 200 feet and widths from three miles at the base to less than one mile near the crown. The deposit underlies an area of some 47 square miles. Of this area only two square miles can be considered unconfined. The transmissivity of the aquifer varies from 100,000 to 380,000 USgal/ft/day in the thick core of the aquifer to 1000 USgal/ft/day along the thin fine grained outer basal fringes. The specific yield in the unconfined area is 0.25. The storage coefficient ranges from 0.01 to 0.0001 in the confined part.

The municipal water development that commenced in 1963 and has steadily increased since that time, combined with private water usage from the aquifer, have resulted in a withdrawal rate of some 700 acre feet per year. If the rate of water withdrawal continues to increase at the current pace the usage will approach 1150 acre feet by 1997 and 1500 acre feet by the year 2007.

Evaluations indicate that the recharge rate to the aquifer prior to development was in the order of 190 acre feet per annum. The present recharge rate is in the order of 338 acre feet per year. This value contains an estimation of induced recharge caused by the lowering of the potentiometric surface within the aquifer due to the groundwater withdrawals. The data available required that many estimations had to be made in selecting the hydraulic parameters on which these values are based.

Withdrawal rates exceeding recharge have resulted in an average yearly decline in the potentiometric surface of 0.7 feet over the past fifteen years. In addition to the decline in the potentiometric surface saline water from the underlying sandstone rock has infiltrated the lower sections of the aquifer. Consequently water quality, particularly in the lower sections of the aquifer, has deteriorated.

The upper segments of the sand and gravel contain potable water. The lower segments contain saline water. The saline water surface rises towards the southern end of the aquifer. Also the water quality in the upper portions of the aquifer deteriorates from north to south.

Above the 250 mg/L chloride line the aquifer contains some 230,000 acre feet of fresh water. Obviously this amount of water can supply the region's water requirements at the current rate of usage for many years. Despite this, the fact that water quality appears to be gradually deteriorating is reason to conserve the resource. In fact, this aspect stresses the need to evaluate the possibilities for artificially replenishing the aquifer.

The aquifer in the northern unconfined segment is open to direct contamination by noxious fluids infiltrating from the surface. Even the zones confined by clay can be contaminated; particularly by noxious fluids that have high specific gravity. To safeguard the aquifer from contamination the area overlying it should be very strictly controlled to ensure that noxious materials, fluids or biocides are not stored, used or disposed of over the aquifer.

Until measures can be taken to replenish the fresh water volume the resource should be conserved for high priority water supplies. All water usage from the aquifer should be metered. The water levels and chemistry within the aquifer should continue to be carefully monitored.

In order to evaluate various development schemes the aquifer should be modelled. However until additional hydraulic data are obtained it is not feasible to accurately model the aquifer system. Additional testing is required to understand the hydrodynamics of the overlying deposits, the interrelationship between the aquifer and the stream channels, the underlying sandstone, segments of the upper aquifer unit and the lower unit.

Under the present circumstances development of new production wells in the unconfined portion of the aquifer would be the most effective approach from the viewpoint of aquifer quantitative management.

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1 INTRODUCTION

The Winkler aquifer system consists of an elongated thick sand and gravel primary unit that extends southeast and northwest of the Town of Winkler and a second similar lesser unit that lies some two miles east of and parallel to the first (Fig. 1). The aquifer is the sole source of water supply for the Town. Therefore the capacity and management of the aquifer is of considerable economic importance to the area.

The objective of this report is to evaluate, based on available information, the hydrogeology, water supply capacity, and water quality relationships of the Winkler Aquifer and to address future aquifer development considerations.

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 were most appropriate to the information.

2 ACKNOWLEDGEMENTS

The aquifer evaluations and the preparation of the report were done under the direction of Mr. M. Austford, Chief of Hydrotechnical Services and Mr. L. Gray, Head, Hydrogeology Section. The report is based on hydrogeologic information that was gathered by a number of previous investigators. In particular the work of L. Gray, M. Rutulis, and A. Pedersen forms the core of the information. Mr. N. Heppner has obtained most of the water level and water chemistry data. M. Rutulis provided a number of concepts about the aquifer situations through discussion. The draft report was reviewed by Messrs. M. Austford, L. Gray, M. Rutulis, J. Petsnik and R. Betcher; their comments greatly improved the presentation. Mr. W. Hnydiuk assisted in the review and compilation of information. Mr. A. Dubicki supervised the drafting which was undertaken by Mr. F. Rogowy. Mrs. D. Morin assisted in the organization of the report and did the typing.

3 PREVIOUS INVESTIGATIONS

The Winkler Aquifer area was first investigated in 1960 as a source of water for the Town of Winkler. Previously water had been obtained from the sand and gravel deposit by means of private wells for water supplies within the Town. However due to the nature of the well construction the water was usually brackish or saline. Several flowing wells were present in the area, particularly south of Winkler.

During the early 1960's the Water Resources Branch carried out substantial drilling and sites for initial fresh water wells were selected to the northwest of the Town (Fig. 2). Also in 1962 the Geological Survey of Canada performed test drilling in the Winkler area and carried out a pumping test in the southeast corner of Sec. 36 - Twp. 3 - Rge. 5, WPM. (Charron 1962). The Geological Survey also carried out test drilling programs in 1966 and 1967. During the interval since the early stages of development various production and observation well construction activities have been undertaken. The last of these actions were the installation of two production wells by the Manitoba Water Services Board and the construction of five water level observation wells by the PFRA in 1981. The work undertaken by the Water Resources Branch is recorded in the Branch's drilling log files as well as in several internal memorandums, by Messrs Gray and Rutulis and in a Municipal Planning Report entitled: Groundwater Resources in the Morden, Stanley, Thompson, Winkler Planning District (Rutulis 1982).

4 DEVELOPMENT HISTORY

The development of the aquifer commenced in 1963 when two wells were installed northwest of the Town by the Manitoba Water Supply Board (Fig. 2). The wells were and are pumped at low rates of 50 gallons per minute or less in order to minimize the drawdown and consequently the tendency of saline water in the lower section of the aquifer to rise towards the well intakes. During 1967 one additional Town well was installed. Three more wells were installed in 1968 and 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 3. 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 (Fig. 3). 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 annual withdrawal estimate is 696.64 acre feet. If the water usage continues to increase at the current rate the withdrawals will rise to 1150 acre feet by 1997 and to 1500 acre feet by 2007.

5 TOPOGRAPHY

The Winkler aquifer is situated along the forefront of the Manitoba Escarpment. Near the Town of Winkler the land surface rises westward at approximately twenty feet to the mile (Fig. 1). The land slope rises rather dramatically six miles west of the aquifer at the Manitoba Escarpment. There is a slight topographic rise towards the north. In general the land over the aquifer is devoid of topographic variations being a uniform lake bottom plain. The only significant variations are those formed by creek channels.

6 GEOLOGY

6.1 Regional Geology

The bedrock under the Winkler Aquifer consists predominantly of Mesozoic shale with minor sandstone units and a few carbonate rock beds (Figs. 4 and 5). The Mesozoic rocks are some 200 feet thick under the Aquifer and increase in thickness to some 1000 feet under the Manitoba Escarpment. The rock bedding slopes towards the west southwest into the Williston structural basin at approximately 15 feet to the mile. The shale rock units rest on Paleozoic Silurian and Ordovician carbonate rocks (Davies et al 1962).

The bedrock surface is overlain by clay-rich till that ranges in thickness from a thin veneer along the upper sections of the Manitoba Escarpment where it is exposed in conjunction with bedrock outcrops, to over 300 feet in depressions in the bedrock surface east of Winkler. The till has a mean thickness in the order of 100 feet in the vicinity of Winkler. The till contains lenses and zones of glaciofluvial sand and gravel formed. The largest of these form the Winkler Aquifer system.

East of the Manitoba Escarpment area the glacial till is covered by lacustrine clay that formed while glacial Lake Agassiz inundated the area. The clay thickness ranges from zero along the Pembina Escarpment forefront to 150 feet thick in the vicinity of Winkler.

West of the Winkler area the clay unit is overlain by beds of sand and silt (Fig. 6) that appear to follow old shallow stream channels and rills in the lake bed surface. These units are up to 20 feet thick. The surficial sand and silt beds tend to phase out east of Winkler.

During the history of Lake Agassiz several sand and gravel beach deposits were formed along the front of the Manitoba Escarpment.

6.2 Winkler Aquifer 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. 1, 5 and 7). 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 (Fig. 4 and 5). 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 part of an extensive system (Rutulis, 1984).

West of the Aquifer the bedrock surface (Fig. 8) 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 valley in the bedrock surface some 200 feet deep. Klassen et al, (1970) 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. 5). Though coarse sand and gravel have been intercepted most logs suggest this 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 rests 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 9) glacial till has been detected under the gravel at some places. At other locations the sand and gravel are almost certainly in contact with shale or sandstone (Figs. 4 and 5). Charron, 1962, reports drilling into 45 feet of sandstone under glacial till in the north-east corner of LSD 14 - Sec. 5 - Twp. 3 - Rge. 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 a mean configuration of one mile wide by 150 feet thick, by 17 miles long (Figs. 5, 7 and 9). The hydrogeologic profile, Figure 9, 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 10. 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.

Surface 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. The area covered by these deposits in the vicinity of the aquifer is shown on Figure 6. Their thickness, in what is herein called the aquifer lateral recharge area, is represented on Figure 11. The vertical relationship to the sand and gravel materials is depicted on the hydrogeologic cross-section Figure 5.

7 HYDROGEOLOGY

7.1 Lower Unit Hydrogeology

The lower aquifer unit consists of the saturated sand and gravel in the bedrock valley. The material appears to be generally fine grained so that in most cases the hydraulic conductivity will be low. There are no aquifer test data for this unit; however, the large thickness could result in substantial transmissivity values. Test wells constructed in the western side of the deposit in 1967 indicate the potentiometric surface was 264 metres a.s.l. 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.

7.2 Upper Unit Hydrogeology

The upper aquifer consists of the saturated elongated deposit of sand and gravel illustrated on Figures 5, 7 and 9. Except for a small area of some two square miles at its north end the aquifer is confined by the overlying clay. Thus, the aquifer has a very small direct infiltration area in the classic sense. The sand and silt beds (Figs. 6 and 11) 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 (Fig. 11).

7.2.1 Groundwater Levels and Potentiometric Surface

Over the past two decades a water level and quality monitoring network has been developed over the upper unit (Fig. 12). Currently the depth to water in wells within the deposit is generally fifteen feet from ground surface. The water levels have generally been in a state of decline since 1971 (Fig. 13). The potentiometric surface slopes from the north towards the south (Fig 14).

7.2.2 Hydraulic Properties

Pumping tests have generally only been done on single wells. However the Geological Survey of Canada performed a multi-well test in LSD 2 - Sec. 36 - Twp. 3 - Rge. 5W near the northern thickest portion of the aquifer (Charron 1962). The geology of the site, depicted in test hole 8F, Charron 1962, strongly suggests that the aquifer at the site is unconfined. Based on this premise interpretation of the data indicates that the transmissivity at the site was 380,000 USgal/ft/day. Considering that the area affected by the test probably has an average saturated thickness of 200 feet (Fig. 7) the apparent hydraulic conductivity is 1900 USgal/ft^2/day. This value is in the range for coarse clean sand and gravel. One aspect of this test that must be considered is that the discharge was pumped onto the ground surface and there was probably some recirculation to the aquifer. This would tend to account for some of the differences in water level readings record in the four observation wells which where all 25 feet from the pumping well, with one located in each major compass direction. The storage coefficient is in the order of 0.20.

Depending on the grain size of the soil and the thickness of the aquifer the transmissivity over the whole aquifer could range from 1000 to 380,000 USgal/ft/day. In the thicker northern sections of the aquifer the transmissivity values based on well construction data are in the range of 100,000 to 380,000 USgal/ft/day. In the central sections of the aquifer, near Winkler, the transmissivity is in the order of 100,000 USgal/ft/day. The transmissivity for the southern sections of the aquifer have not been evaluated. However as the aquifer is thinning in that direction the transmissivity will almost certainly be decreasing. The storage coefficient values realistically should range from 0.0001 to 0.01. The Specific Yield should be in the range 0.01 to 0.25. The variation in values 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. The transmissivity evaluation indicates that the data is not sufficient to define the aquifer's water transmitting capabilities to the level required for accurate digital modelling.

7.2.3 Groundwater Flow

The potentiometric surface slopes southerly along the axis of the aquifer (Fig. 14). 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 so that the groundwater flow is reduced or nonexistent.

8 GROUNDWATER CHEMISTRY

8.1 Groundwater Chemistry of the Lower Unit

The water quality in the lower unit of the Winkler Aquifer is generally unknown. The one sample that was available indicates that the water on the north west corner of the known parts of the system had a total dissolved solids of 786 mg/L and a chloride ion concentration of 72 mg/L in 1967. Considering the geologic setting of the aquifer unit this is an excellent water quality.

8.2 Groundwater Chemistry of the Upper Unit

Water quality in the bottom section of this aquifer where it rests on the Swan River Formation is generally brackish to saline. 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. This feature of the aquifer has a paramount influence on all groundwater development activities.

The water quality in this aquifer varies both with depth and from north to south. Water quality in the northern recharge area is excellent. The total dissolved solids were 441 mg/L in the Roland supply well when it was installed in October 1977 while the total dissolved solids in the southern Rhineland Community well was 1006 mg/L when it was installed in October 1975. The Roland Community well water quality had deteriorated to 807 mg/L total dissolved solids in June 1983. The water quality generally is better than the drinking water standards in the Winkler municipal wells. However, as discussed by Rutulis (1983), the saline water from below rises to contaminate the fresh water if the conservative pumping rates are exceeded. The water quality in the observation well adjacent to the Rhineland Community has deteriorated from 1790 micromhos/cm in January 1983 to 2030 micromhos/cm in October 1986. Over the same interval the chloride ion concentration increased from 185 mg/L to 270 mg/L. At the same site an observation well open at the 150 foot depth has shown a gradual chloride increase from 460 mg/L to 960 mg/L over the same time interval. In considering the ionic increases it must be remembered that the observation wells are located inside the pumping well's drawdown cone and therefore the water quality deterioration may be localized. In general the data indicates the water quality in the aquifer is slowly deteriorating. The fact that the Roland Community well is immediately adjacent to the prime recharge area makes the water quality deterioration in it particularly ominous.

Most of the chemical observation wells are close to a Town pumping well. However observation well No. 4 (Fig. 12) is located at some 300 feet from a Town pumping well. The intake zone for this well is some 180 feet below ground level in the lower section of this aquifer. The hydrograph of Electric Conductivity (Fig. 13) shows that the water quality in the lower sections of the sand and gravel is slowly deteriorating. This appears to be occurring roughly in parallel with the increases in withdrawal rates and the decline in the elevation of the potentiometric surface. The situation depicted on Figure 13 is occurring to similar or lesser degrees in most of the other deep water quality observation wells.

Another factor that must be considered in assessing the long term water quality variations in the aquifer is that as the body of saline water under the fresh water increases the diffusion of ions from the concentrated solution into the fresh water will increase. Therefore even if there were no increase in the vertical hydraulic head driving the saline water upward the zone of salinity is likely to slowly expand.

The large body of fresh water was probably established during the last phase of Glacial Lake Agassiz. If this postulation is correct the water in the lower fresh water parts of the aquifer should be 10,000 years old. Therefore there is the possibility that if oxygen 18, deuterium, and carbon 14 water samples were obtained and analysed the age of the water could be assessed. Also some indication of the volume of modern water could be obtained.

9 GROUNDWATER CONTAMINATION

The unconfined sections of the aquifer and particularly the gravel quarry area (Plate 1) are very susceptible to direct infiltration of fluid contaminants. This area should be protected in a very strict manner. Considering the fact lubricants and fuels have been used in the quarry and that it is open to the public so that dumping could take place, it would be amazing if some contaminants have not already entered the aquifer.

Most of the aquifer is confined below substantial thicknesses of glacial lake clay and till. However there is the possibility that noxious fluids with high specific gravities could seep through the clay and contaminate the aquifer.

Surface water seeping through the bottoms of Shannon and Deadhorse Creeks into the aquifer is a potential source of contamination.

10 RECHARGE RELATIONSHIPS FOR THE UPPER UNIT

The most obvious source of fresh water replenishment for the aquifer is the gravel quarry at the north end (Plate 1). 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 (Figs 6, 9 ,10, and 11). If the fifteen year mean discharge rate of the Pine Creek Basin, (Render, 1984) 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 use of the mean discharge value from the Pine Creek Basin compensates for annual variations in precipitation.

The second zone has a silty clay-clay cover that ranges up to 10 feet thick (Fig. 10). Under even small gradients the infiltration rate for this zone would be close to that for the silt and fine sand area. Therefore the availability rate of 0.109 feet of water per annum 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 part of the Winkler aquifer. This unconfined silt and sand aquifer covers an area of some 30 square miles. However, much of the estimated 2100 acre feet that infiltrates, these soils discharges relatively quickly in the spring and early summer into Deadhorse and Shannon Creeks or is transpired throughout the summer. Reasonable estimates of the flow area hydraulic conductivity and the water table gradients towards the aquifer's prime intake zone indicate the conditions are insufficient to move more than a small portion of this water into the aquifer. The outline and thickness of these deposits are shown on Figures 6 and 11.

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 Figures 5 and 11.

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. 11). The water table is generally five feet below ground level. Thus the saturated thickness can be considered to be five feet. As shown on Figure 11 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 USgal/ft^2/day.

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

$$Q \text{ acre feet} = \frac{100 \times 2.6 \times 5280 \times 5}{6.229 \times 43{,}560}$$

$$\therefore \quad Q \text{ acre feet} = 25 \text{ acre feet}$$

Prior to development the above described recharge systems replenished the aquifer. The estimated total recharge from these sources is 191 acre feet per year. It is interesting to observe on Figure 13 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 levels caused steadily increasing downward hydraulic gradients through the aquifer roof. 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 withdrawal (Fig. 13) combined with and resulting from above mean rainfall. The steep recovery in 1986 coincides with above mean precipitation during the spring and early summer. Unless the above mean precipitation continues or the withdrawal rates are reduced the water levels will recede to below the winter of 1984/85 levels within a year.

10.1 Induced Recharge Through The Clay

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 directly increased as the water levels declined. Currently 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's clay cover thickness and the approximate outline of the aquifer sand body are shown on Figure 10. 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 optimistic for the lower section of the thicker clay units. Using this hydraulic conductivity estimate the estimated downward leakage for each clay thickness range over the upper aquifer unit is as follows:

TABLE OF INDUCED RECHARGE THROUGH THE CLAY

THICKNESS (ft)	GRADIENT	AREA (sq. miles)	ACRE FEET/YR
10 - 20	.67	1.671	15.8
30 - 30	.40	6.033	34.1
30 - 40	.286	3.620	14.6
40 - 50	.222	2.891	9.08
50 - 60	.182	5.037	12.9
60 - 70	.154	3.318	7.21
70 - 80	.133	2.700	5.09
80 - 90	.118	2.081	3.46
90 - 100	.105	2.566	3.82
100- 110	.095	3.169	4.26
110 - 120	.087	5.329	6.55
120 - 130	.080	1.252	1.42
130 - 140	.074	3.141	3.29
140 +	.070	2.642	2.67

Induced Yearly Recharge Through The Clay 124 ac. ft.

10.2 Induced Recharge Through The Stream Beds

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 indicate 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 estimation 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 placed at 20 feet. Based on these gross assumptions the 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. This value is therefore the current non-mining yield of the upper unit of the Winkler Aquifer. The original natural rate of replenishment was approximately 190 acre feet per year.

11 DISCUSSION OF THE WATER BUDGET OF THE UPPER UNIT

Comparison of the discharge estimates with the postulated yearly recharge rate of 338 acre feet indicates that fresh water is presently being mined from the aquifer at a rate of 359 acre feet per year. The rate of water withdrawal shown on Figure 3 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. 13) 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. 10). The declining water levels induced a gradual increase in leakage through the 45 square miles confined by the clay which accumulated to 930 acre feet over the fifteen years. Assuming that the unconfined area of the aquifer north of Deadhorse Creek has a specific yield of 0.20 the 10.5 foot water level decline would withdraw 2728 acre feet from storage. A slightly lower specific yield was estimated because the outer portion of this area has a considerable clay content. 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 have been arrived at by a series of estimations they do coincide reasonably. Presumably the difference would 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 mean precipitation reducing water demand and increasing the recharge rate in the unconfined area the water level decline stopped and some recovery occurred (Fig. 13). However with the apparent potential for increased usage (Fig. 3) there is little doubt that the water level decline will commence again once the precipitation events return to mean 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 appears that of the current 359 acre feet of fresh water mining 55 percent or 210 acre feet will be withdrawn from storage and the remaining 175 acre feet 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 9 it can be seen that once another ten feet of drawdown occurs the unconfined area of the deposit will increase considerably. Then most of the residual water will come 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 mined from the aquifer each year. In fact, if the saline water influx was not reducing the water level decline the gradient across the clay unit would increase and there would be an increase in recharge. Unfortunately the water quality in the clay is usually not good and recharge from this source is not likely beneficial to overall aquifer water quality.

Despite the above considerations there is little likelihood that the water system is in immediate jeopardy. Indications are that there are 230 000 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. Thus as long as the development is done carefully so as not to cause the saline water to rise dramatically upward through the fresh water zone the aquifer should sustain the region's water requirements for many years.

CONCLUSIONS

1. The Winkler Aquifer system is a major and presently the sole source of fresh water for the Winkler area. The 230,000 acre feet of stored potable water is sufficient to supply the area for many years. However, even at the present relatively small rate of usage, the aquifer water levels are receding. This means that there is going to be more and more upward stress forcing salt water into the fresh water zones. That is, the fresh water zone is going to shrink both from above and below and by chemical diffusion. This source of fresh water could only be replaced at great expense. Therefore extraordinary groundwater management measures should be taken to preserve and protect the fresh water in it until safe economic alternatives can be developed.

2. The available data indicates the Winkler Aquifer system is composed of a major upper unit and a lower poorly defined unit. The lower unit has not been developed.The current rate of withdrawal of 700 acre feet from the upper unit exceeds the natural rate of recharge by a considerable amount. The original natural recharge rate was in the order of 190 acre feet per year. The current overall rate of recharge to the aquifer is estimated at 300 acre feet per year or 155 Imperial gallons per minute. The rate of water withdrawal is in the order of 700 acre feet per year or 361 Imperial gallons per minute. The deficit is 400 acre feet per year or 206 Imperial gallons per minute. The water withdrawal rates have risen to the point where it is not feasible to reduce the consumption to the natural mean rate of replenishment. In fact the indications are that the withdrawals will approach 1150 acre feet by 1997 and 1500 acre feet by 2007.

3. Due to the fact leakage from above and below do not equal the rate of withdrawal, aquifer water levels have declined since 1971 some 10.5 feet, or at the average rate of 0.70 feet per annum. Unless the rate of withdrawal is reduced or measures are taken to increase recharge the water levels will continue to decline.

4. The declining water levels have induced downward seepage through the clay that confines most of the aquifer. The hydraulic parameters of the sediments overlying the aquifer can only be surmised. Thus this source of recharge is difficult to quantify. The water quality in the clay beds overlying the the aquifer is not known. However as the water quality in the clay is usually poor this water source is probably not totally beneficial.

5. The water level relationships and soil conditions under and along Shannon and Deadhorse Creek channels are not known precisely enough to allow accurate analysis of the effects of the creeks on the aquifer.

6. Further water mining below the present water table elevations, which is almost certain to occur under the present withdrawal conditions will enhance the prospects for artificial recharging the aquifer. On the converse, further water level declines will increase the movement of poor quality water into the fresh water sections of the aquifer.

7. There is a high probability that the problem of inadequate recharge to the aquifer system could be reduced or alleviated by artificial recharge schemes.

8. The aquifer in the northern upper portion contains some 230,000 acre feet of water with chloride concentrations less than the drinking water standard of 250 mg/L. The bottom sections of the upper unit contain saline water. Water quality in the lower sections of the Aquifer are gradually deteriorating. There do not appear to be any barriers to the vertical movement of saline water from the lower sections of the aquifer to the top portions. Therefore under the current circumstances the water quality deterioration will continue to move upward.

9. Analysis of the Oxygen 18, Deuterium, and Carbon 14 content of the aquifer water could assist in determining the age relationships of the water stored in the aquifer.

10. There are no provisions to protect the area over the aquifer from being contaminated with noxious materials, fluids and biocides. This is particularly important over the northern part of the aquifer where it is unconfined and therefore open to direct infiltration of contaminants.

11. The transmissivity of the central sections of the upper unit of the Winkler Aquifer ranges between 100,000 and 382,000 USgal/ft/day in the northern segments of the aquifer; and are in the order of 100,000 USgal/ft/day in the central parts of the aquifer. The transmissivity for the southern portion of the aquifer have not been determined. The transmissivity along the flanks of the deposit are much lower than the above values declining to less than 1000 USgal/ft/day. The storage coefficient for the aquifer ranges from 0.01 in the confined semi-confined and northern sections to 0.0001 in the deeply buried thinner southern areas. The specific yield in the northern unconfined sections of the aquifer is estimated to range between 0.1 and 0.25.

However, in detail the hydraulic parameters are not well enough defined to allow accurate digital modelling of the aquifer system.

12. The northern segment of the Winkler Aquifer having high transmissivity and specific yield values would accommodate relatively high capacity wells while producing small values of operational drawdown. Also the wells could be placed in the order of 500 feet apart without significant interference. However pumping more than the recharge rate directly from the recharge area may increase the rate of detrimental water quality changes throughout the whole of the aquifer.

13. The nature of the physical and hydraulic contact between the Swan River Formation and the bottom of the Winkler Aquifer has not been defined. Piezometer installations in the sandstone units would be required in order to determine the quantitative relationships between the Swan River sandstone and the Winkler Aquifer.

14. The hydrogeology of the lower unit of the Winkler Aquifer system has not been defined. This part of the aquifer system will have to be studied if its value to the area is to be assessed.

RECOMMENDATIONS

FOR IMPLEMENTATION IMMEDIATELY:

1. Water diversions from the Winkler Aquifer should be restricted to municipal and domestic use.

2. Measures should be taken to ensure that noxious materials, fluids or biocides are not stored, used or disposed of over the aquifer area. The unconfined portion of the aquifer is particularly susceptible to contamination and should be strictly controlled to the extent of being fenced analogous to a urban water reservoir.

3. Water quality samples should be taken from various places in the aquifer and analysed for chemistry, heavy metals, petroleum products, and biocides, particularly in the northern unconfined portion including the open ponds in the gravel quarry

4. The present water level and water quality observation program adjacent to the pumping wells should be continued and expanded where necessary.

5. In the confined portion of the aquifer the practice of spacing shallow penetrating new production wells approximately one-half mile apart and limiting the pumping rate to a maximum of 50 imperial gallons per minute should be continued.

6. In the unconfined portion of the aquifer, shallow penetrating new production wells can be placed 500 feet apart and pumped at 200 imperial gallons per minute. However, it is essential that tests prove that the aquifer in the vicinity of these wells is actually reacting in an unconfined manner. Under the present circumstances it would appear

that production well development in the unconfined portion of the aquifer would be the most effective approach from the viewpoint of aquifer quantitative management.

7. Even after higher capacity wells are in operation the present wells should be continued in operation to maintain a flow of fresh water towards the southern part of the aquifer and to reduce the concentration of the drawdown effects.

FOR IMPLEMENTATION WITHIN FIVE TO TEN YEARS.

8. Steps should be taken to accurately define the hydrologic budget of the aquifer system.

9. Pumping tests either of the standard formal type or by utilizing established production wells should be undertaken to define the hydraulic parameters of the aquifer.

10. Additional observation wells at different depths in various portions of the aquifer away from the vicinity of pumping wells should be established to better determine the effects of development on water quality in the lower parts of the aquifer.

11. Oxygen 18, deuterium and carbon 14 water samples should be taken and analysed to evaluate the age of the water in various portions of the aquifer.

12. Surveying, test drilling, soil sampling, shallow observation well installation, and comprehensive surface water and groundwater quality sampling should be done along the Shannon and Deadhorse Creek channels so that the relationships between the creeks and the aquifer can be

accurately understood. Knowledge of these relationships is also important to any evaluation of artificial recharge to the aquifer.

13. Test work should be done to evaluate the hydraulic parameters of the clay and glacial till beds overlying the aquifer. These should be understood in order that the effect of downward percolation into the aquifer can be assessed.

14. To determine the effects of overburden water on the aquifer water quality observation well nests should be installed in the deposits overlying the aquifer.

15. Test drilling and observation well construction should be done to assess the interconnection between the Swan River Sandstone and other sandstone beds and the lower segments of the Winkler Aquifer. This definition should be undertaken to establish the capacity of the sandstone to inject saline water into the bottom of the Winkler Aquifer at the points of contact so that the points of contact can be avoided as locations for production wells in the Winkler Aquifer. Also water quality and water level observation wells should be established in the Swan River Sandstone in the vicinity of the original Town of Winkler wells and under the northern segment of the aquifer.

16. The hydrogeologic conditions in the lower aquifer unit and the postulated buried valley should be investigated and their potential to contribute to the region's water supply determined.

17. The aquifer system should be modelled and the model used to determine the effects of various development scenarios.

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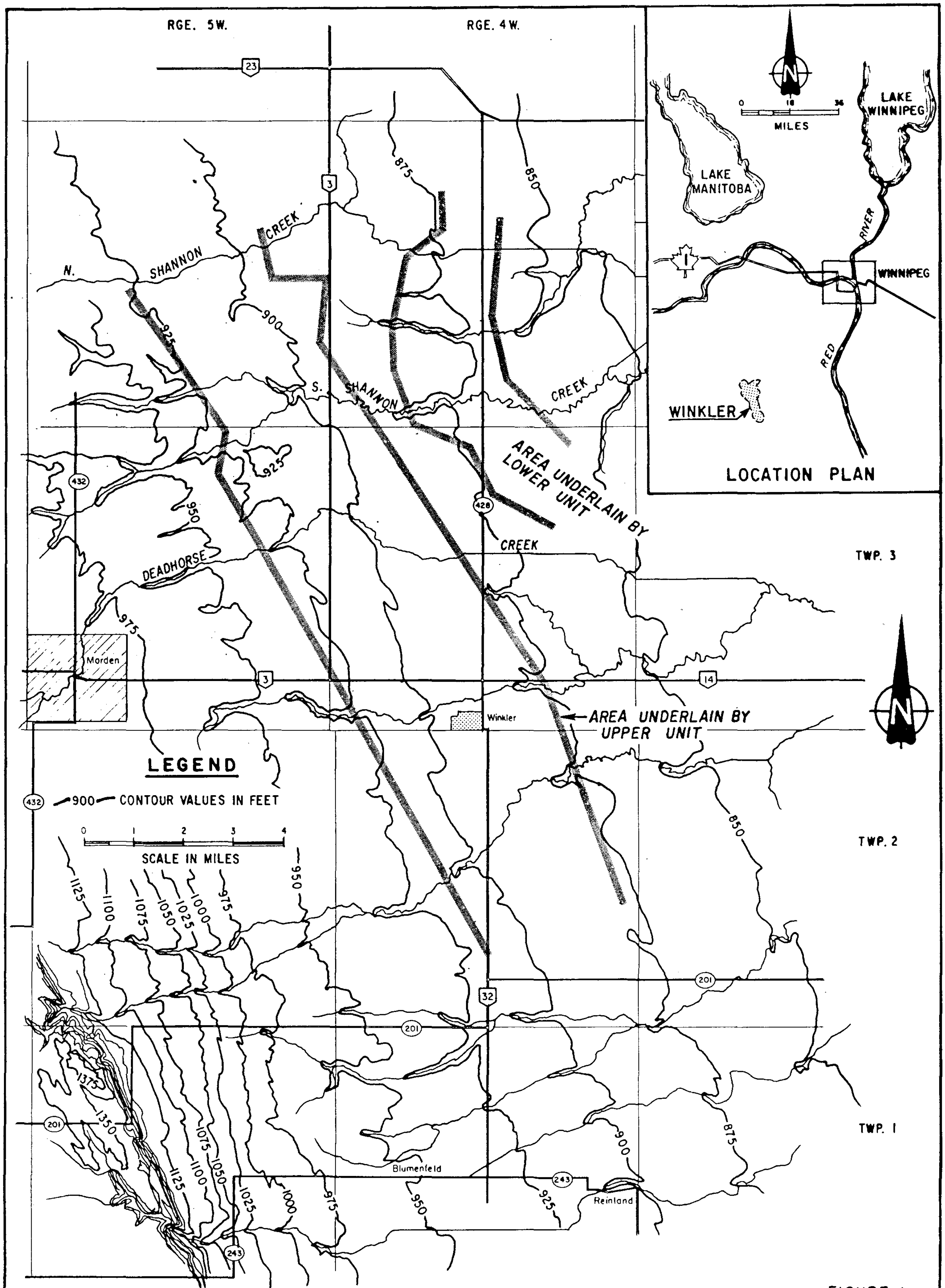


FIGURE 1

DRAWN F.B.R.	Manitoba Natural Resources Water Resources	WINKLER AQUIFER
CHECKED		LOCATION AND TOPOGRAPHY
PREPARED	SUBMITTED / APPROVED	SCALE / DATE / SHEET / FILE NO.

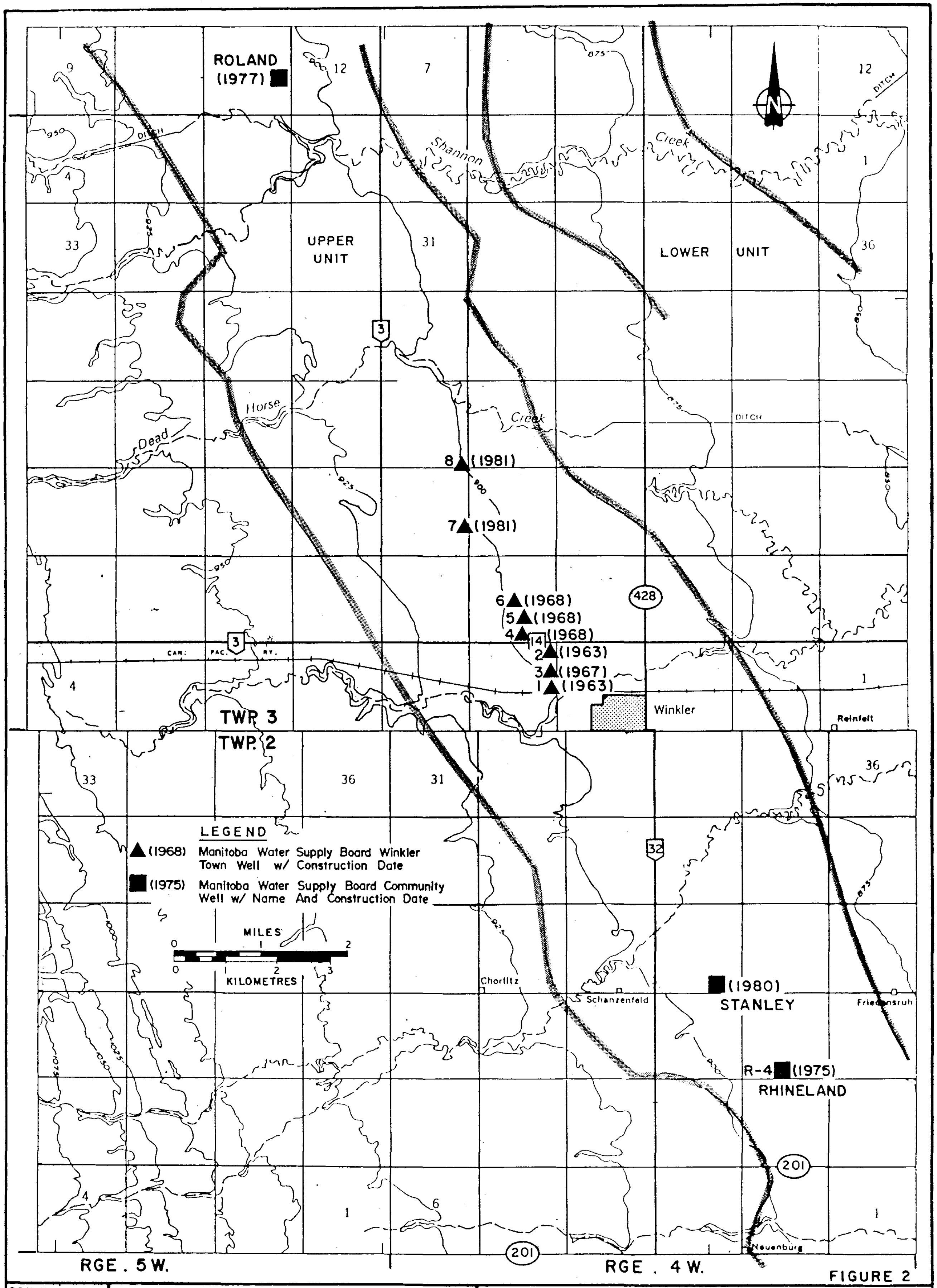


FIGURE 2

DRAWN F.B.R.	**Manitoba Natural Resources** Water Resources	WINKLER AQUIFER
CHECKED		**PRODUCTION WELLS**
PREPARED		

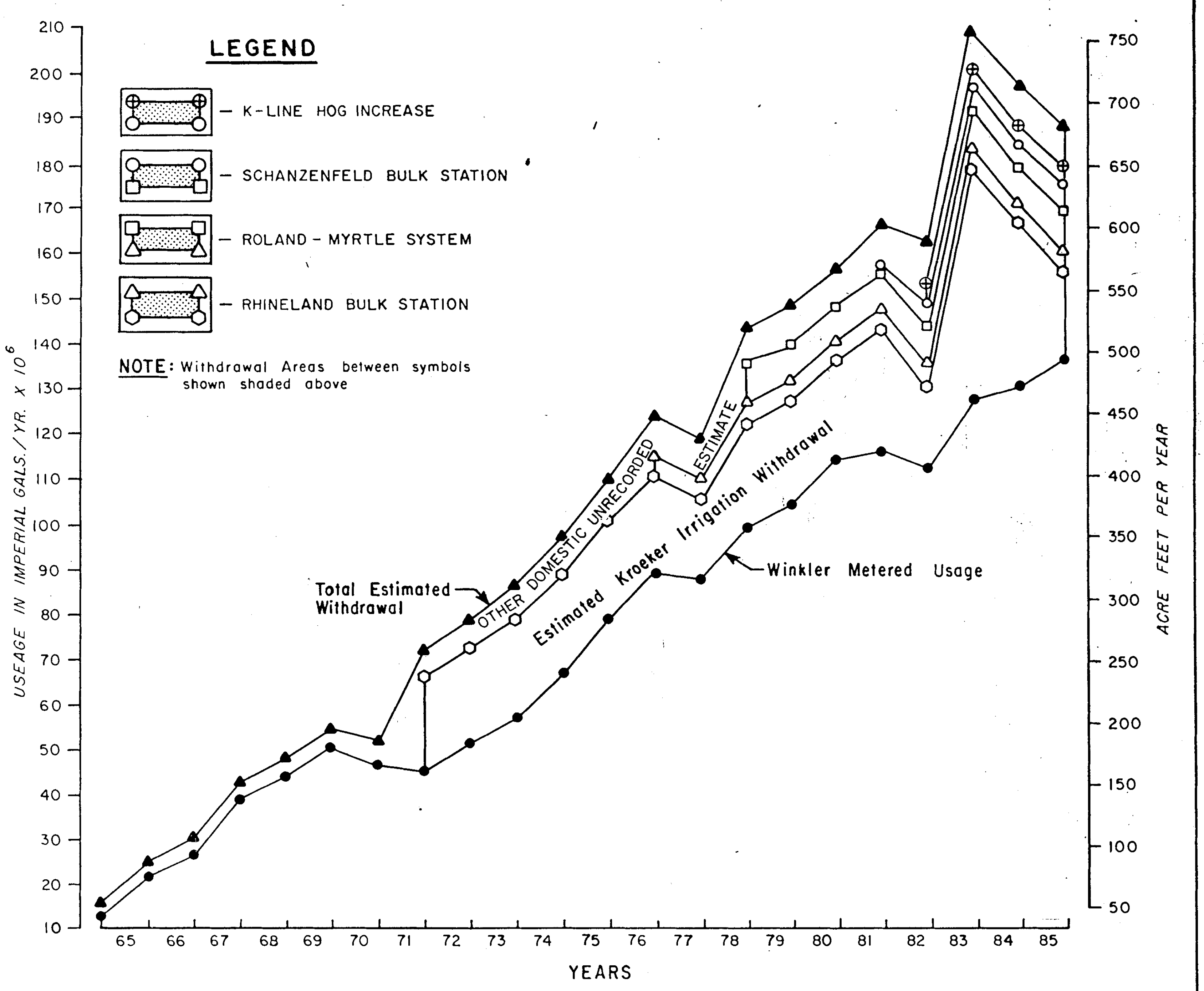


FIGURE 3

WINKLER AQUIFER

WATER WITHDRAWALS

Manitoba
Natural Resources
Water Resources

DRAWN F.B.R.

CHECKED

PREPARED

SUBMITTED

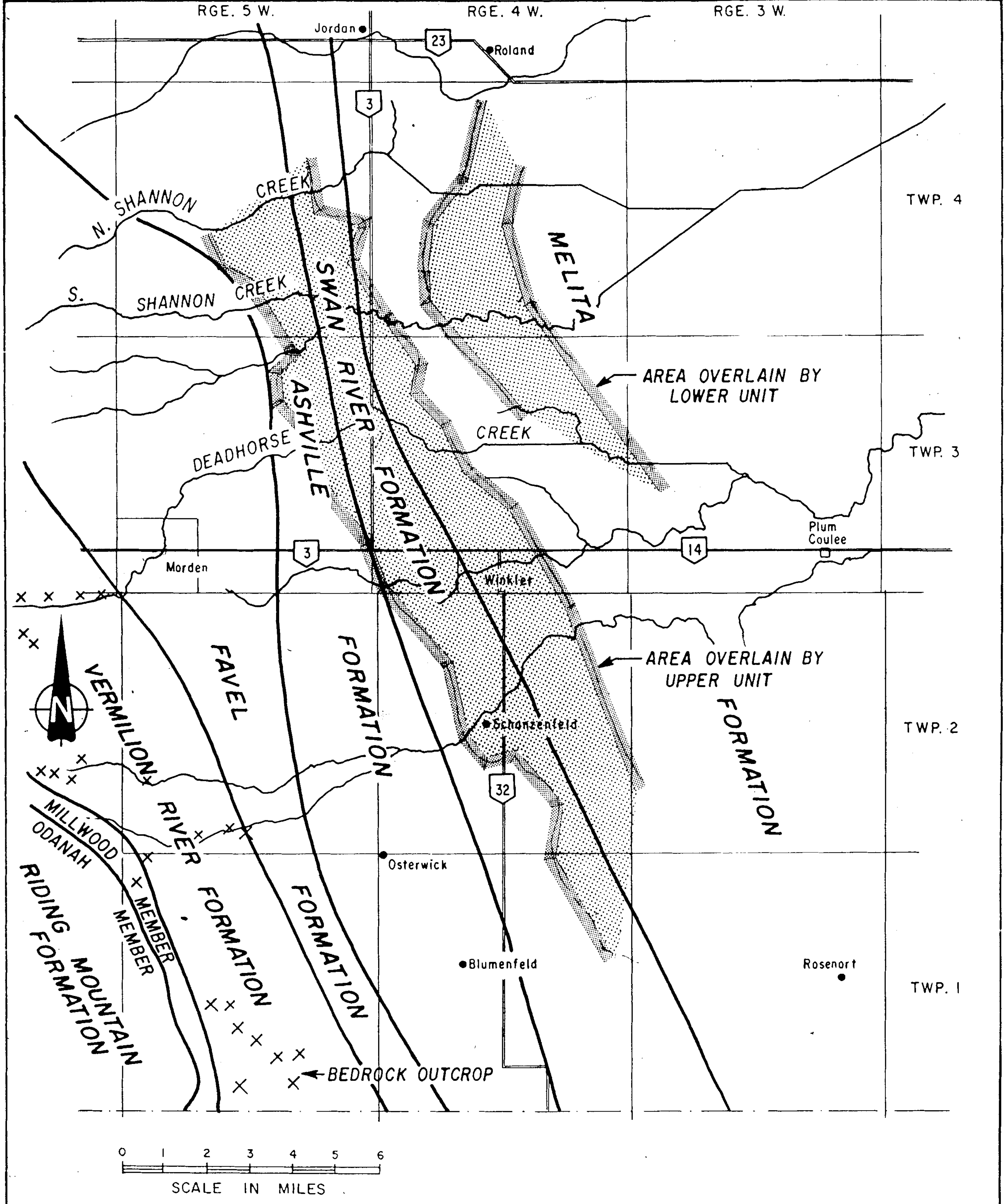
APPROVED

SCALE

DATE

SHEET

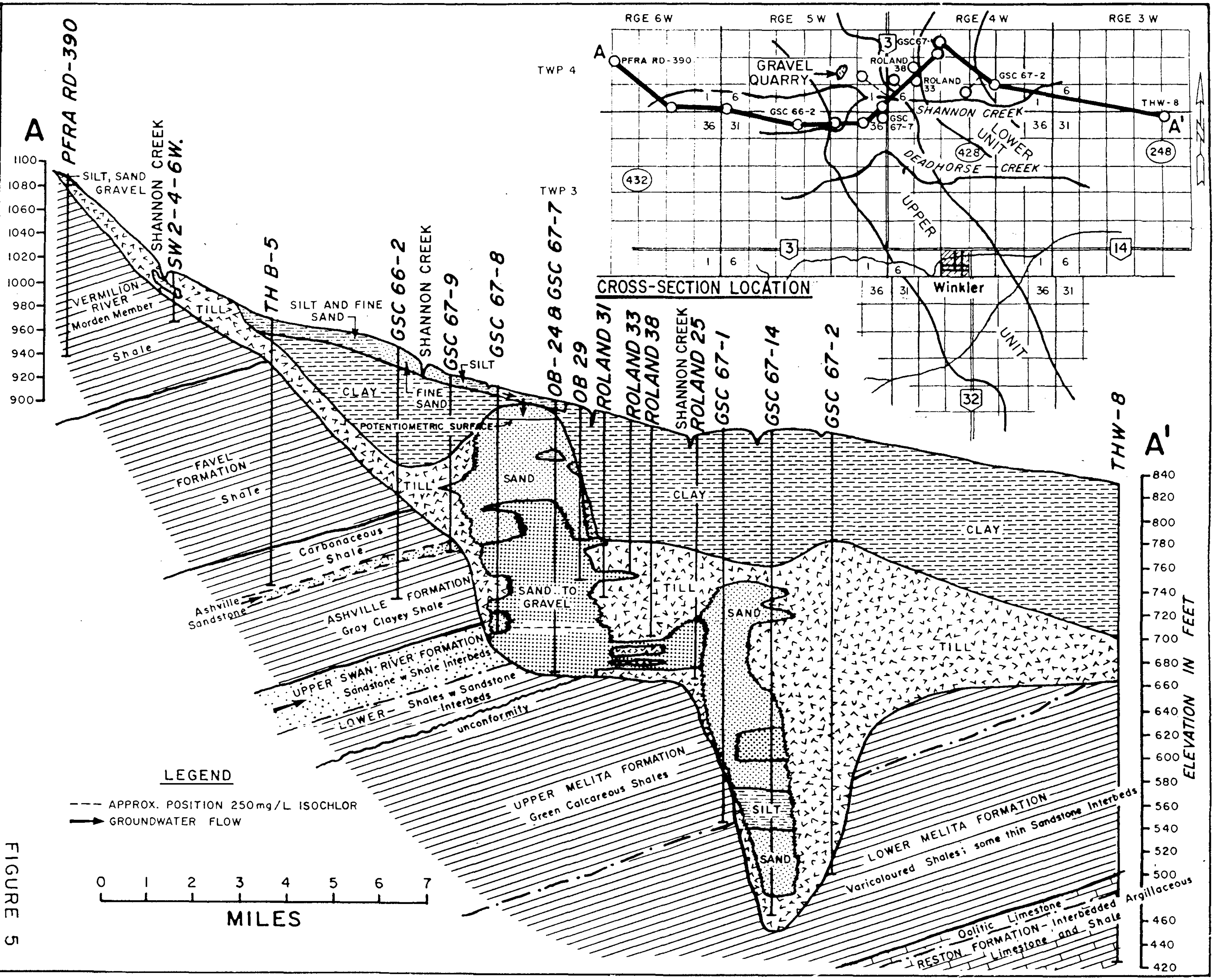
FILE NO.



After: SIE and LITTLE, 1976 & 80

FIGURE 4

DRAWN F.B.R.	Manitoba Natural Resources Water Resources	WINKLER AQUIFER
CHECKED		BEDROCK GEOLOGY
PREPARED	SUBMITTED / APPROVED	



Manitoba Natural Resources
Water Resources

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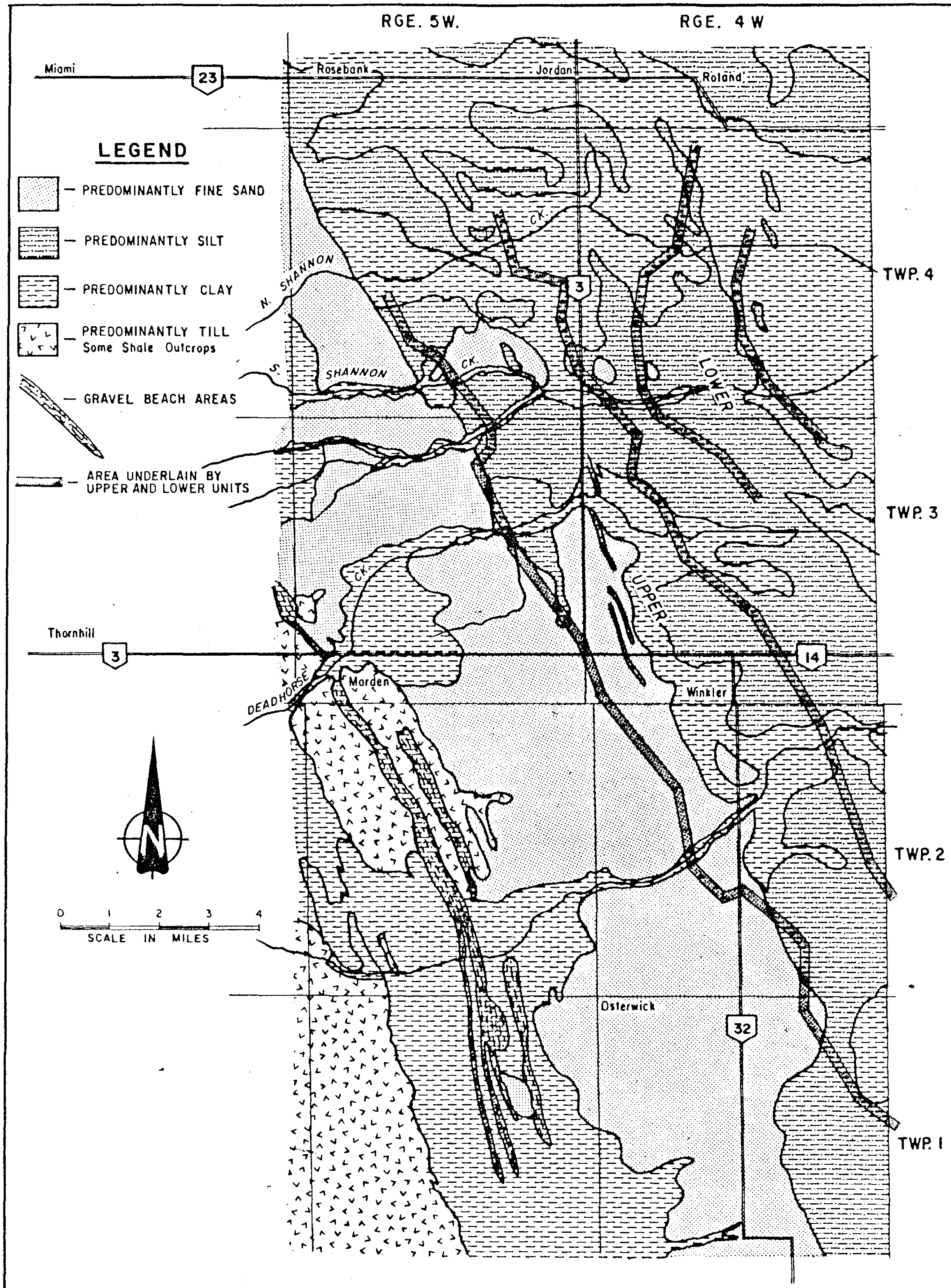
CHECKED
PREPARED F.W. Render
SUBMITTED
APPROVED

WINKLER AQUIFER
HYDROGEOLOGIC CROSS-SECTION

SCALE
DATE
SHEET
FILE NO.

FIGURE 5



After: ELLIS and SHAFER, 1943

FIGURE 6

DRAWN F.B.R.	Manitoba Natural Resources Water Resources	WINKLER AQUIFER SURFACE DEPOSITS
CHECKED		
PREPARED F.W. Render	SUBMITTED / APPROVED	SCALE AS SHOWN / DATE / SHEET OF / FILE NO. 10·1·7·1234

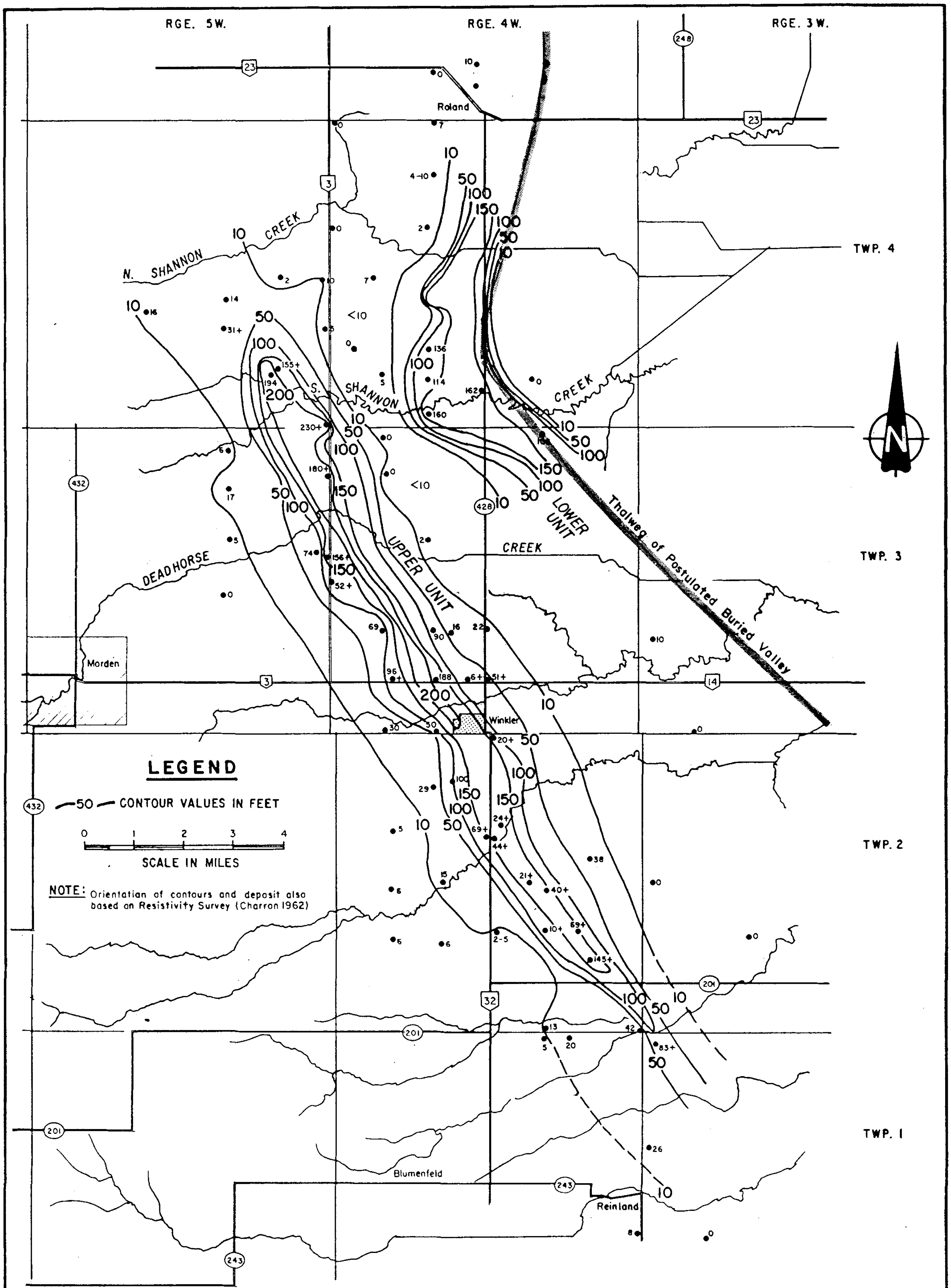


FIGURE 7

DRAWN F.B.R.

CHECKED

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Manitoba Natural Resources
Water Resources

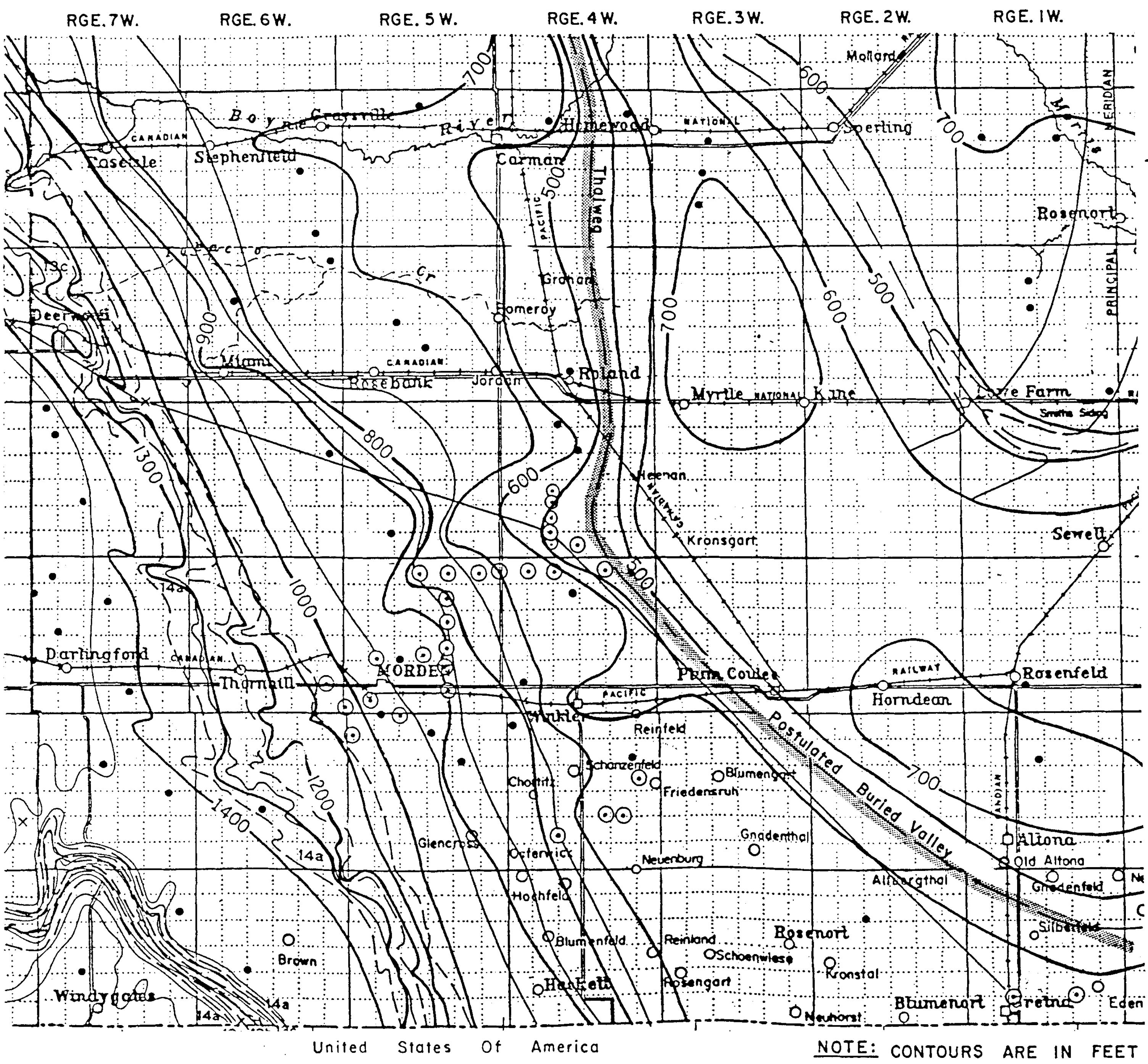
SUBMITTED

APPROVED

WINKLER AQUIFER

SAND AND GRAVEL THICKNESS

SCALE | DATE | SHEET | FILE NO.



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Manitoba Natural Resources

Water Resources

WINKLER AQUIFER

BEDROCK SURFACE TOPOGRAPHY

FIGURE 8

DRAWN F.B.R.

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SUBMITTED

APPROVED

SCALE

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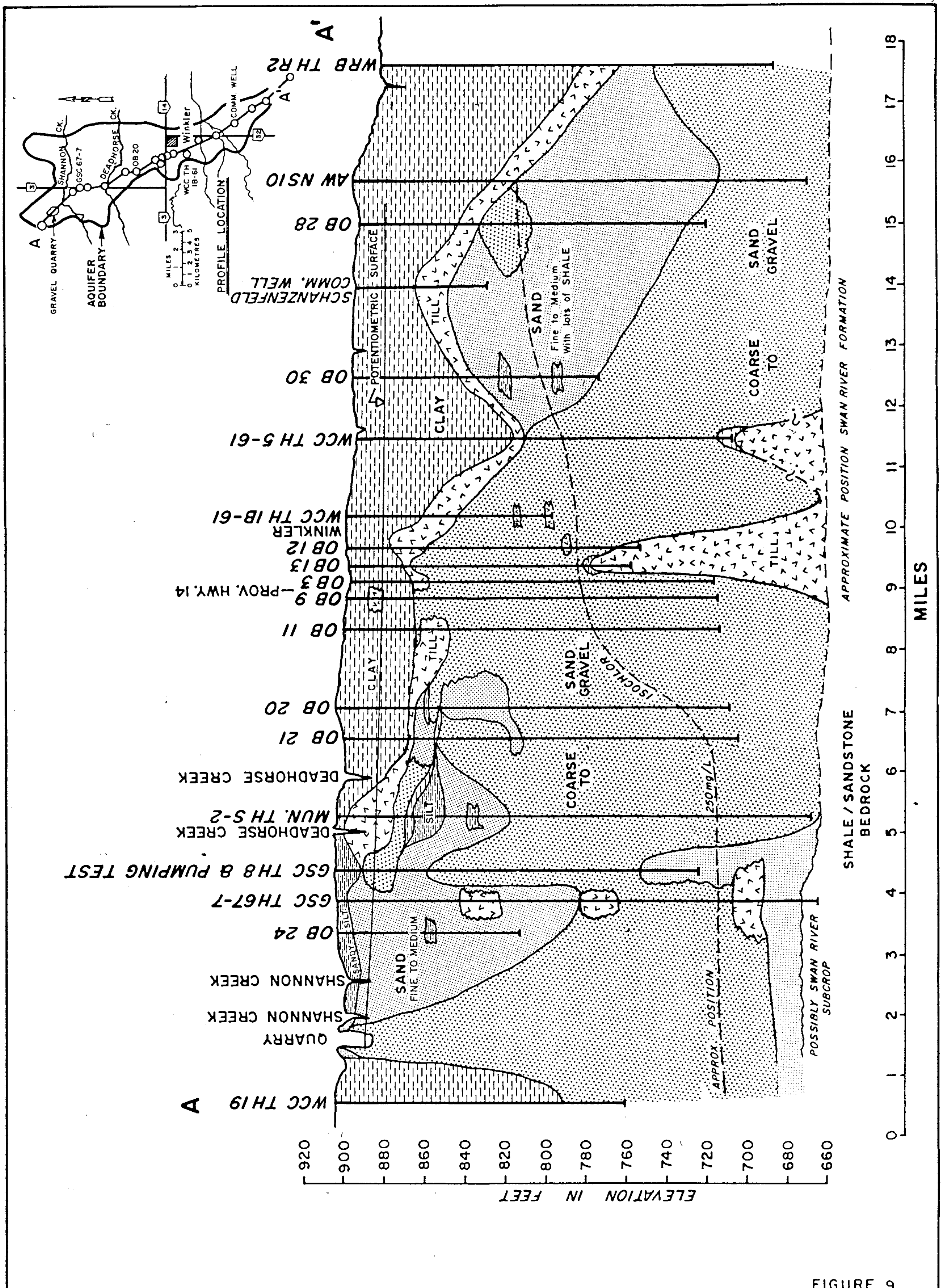


FIGURE 9

DRAWN F.B.R.	Manitoba Natural Resources Water Resources	WINKLER AQUIFER HYDROGEOLOGIC PROFILE
CHECKED		
PREPARED F.W.R. / W.H.	SUBMITTED / APPROVED	SCALE / DATE / SHEET / FILE NO. 10-1-7-1234 [illegible]

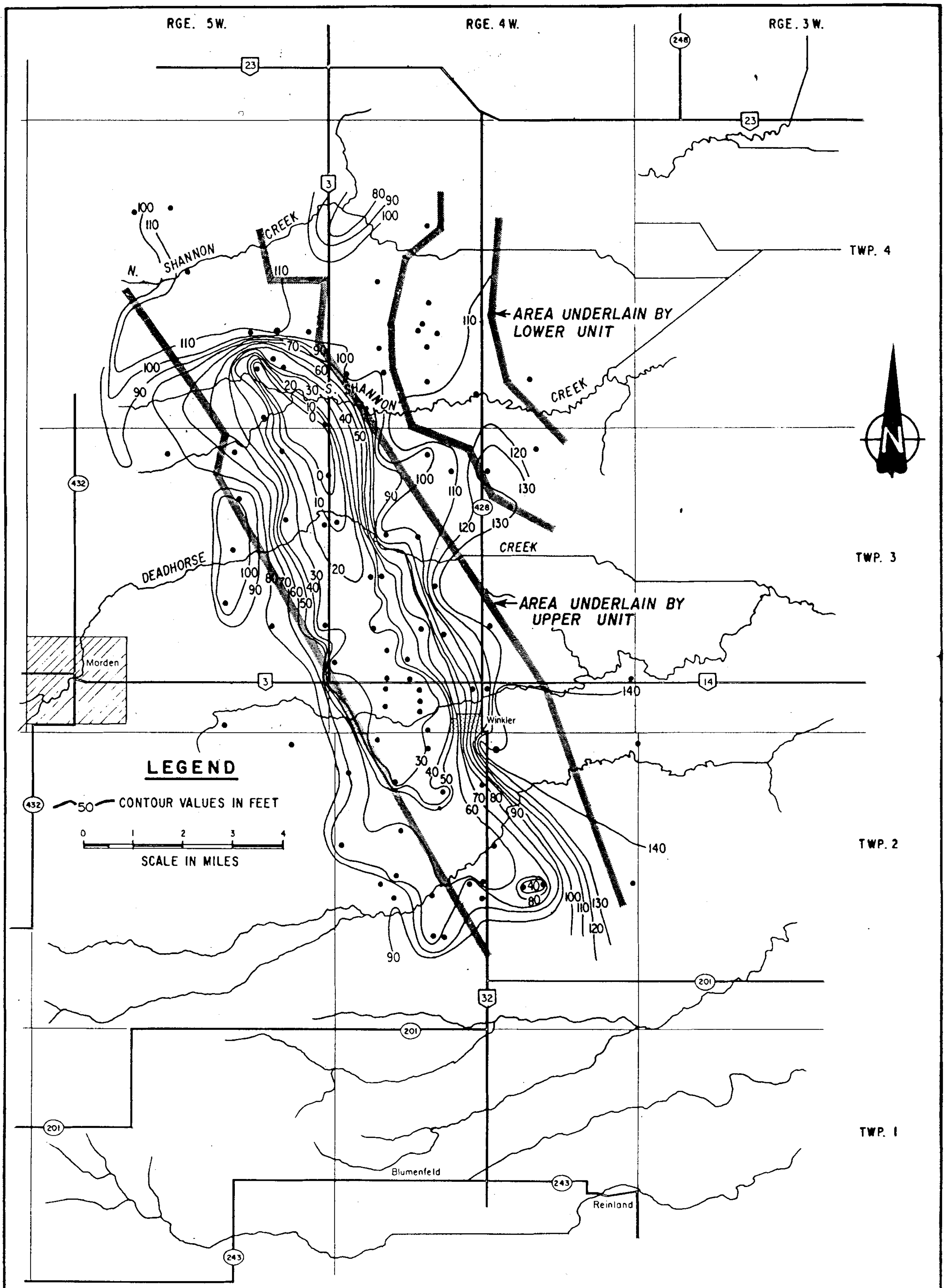


FIGURE 10

DRAWN F.B.R.	Manitoba Natural Resources	WINKLER AQUIFER
CHECKED	Water Resources	CLAY THICKNESS
PREPARED F.W.R. / W.H.	SUBMITTED / APPROVED	SCALE / DATE / SHEET / FILE NO.

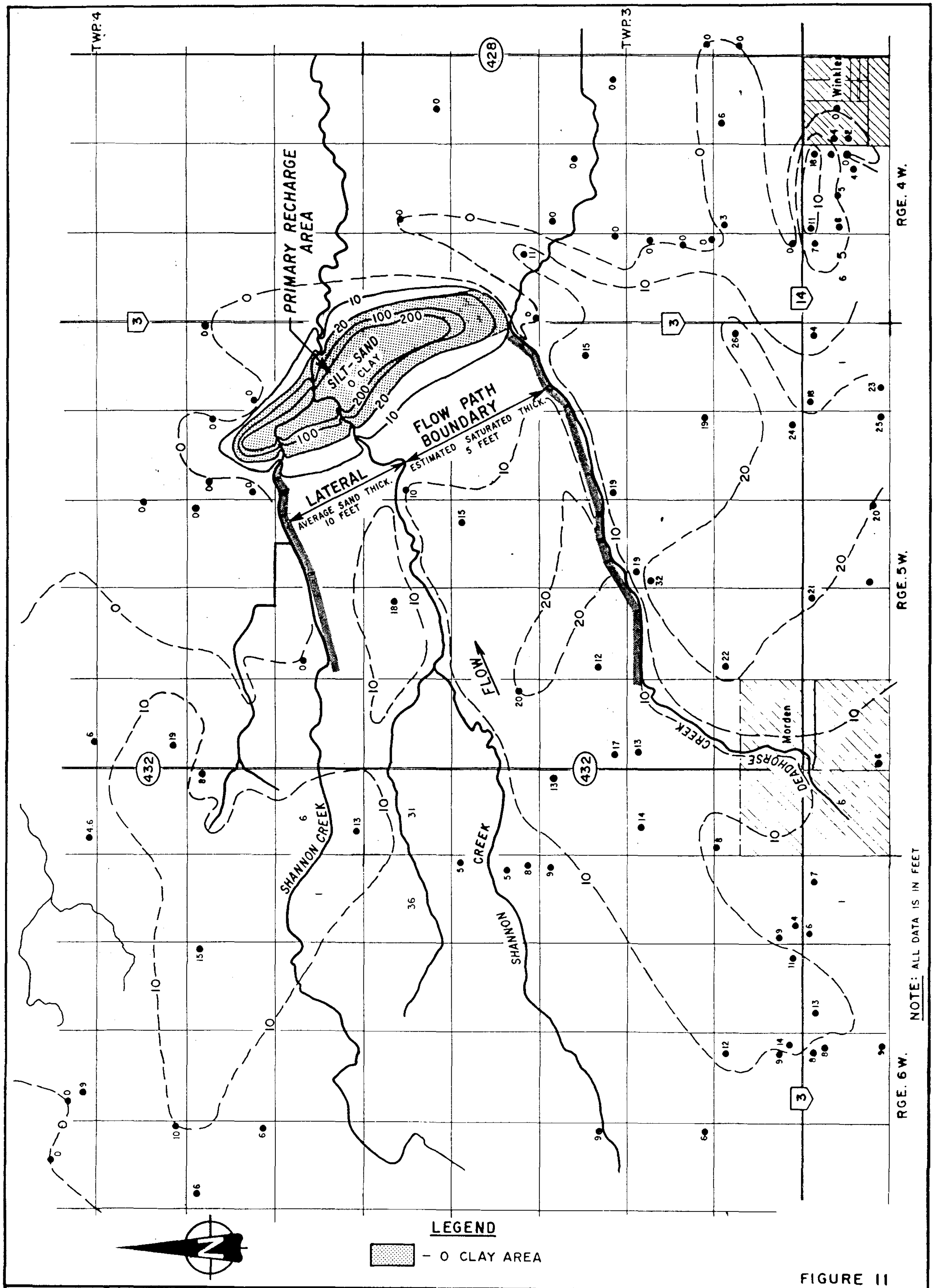


FIGURE 11

DRAWN F.B.R.	Manitoba Natural Resources Water Resources	WINKLER AQUIFER LATERAL RECHARGE SOURCE AREA SURFICIAL SAND-SILT THICKNESS
CHECKED		
PREPARED WH/EWR	SUBMITTED / APPROVED	SCALE / DATE / SHEET / FILE NO.

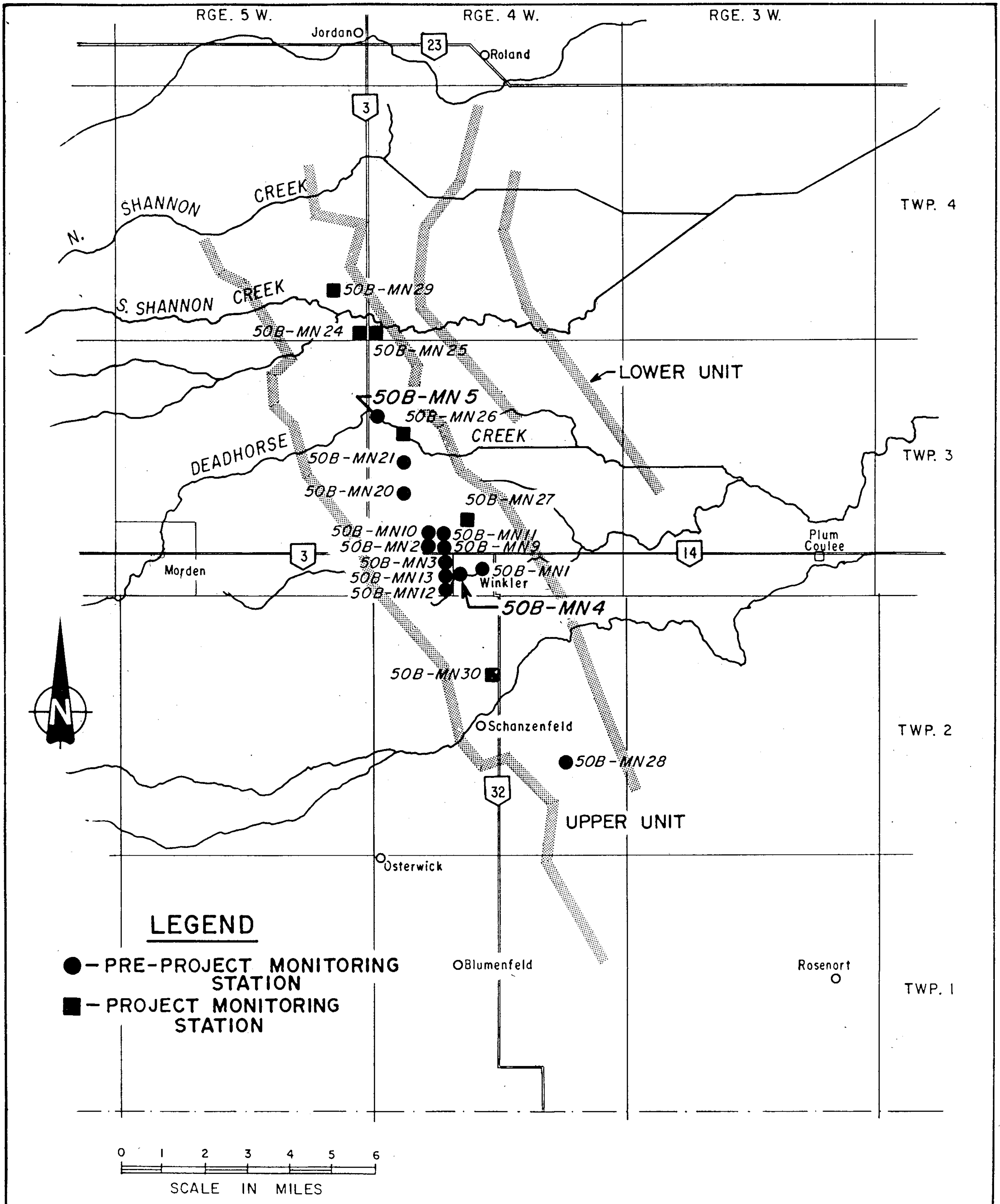


FIGURE 12

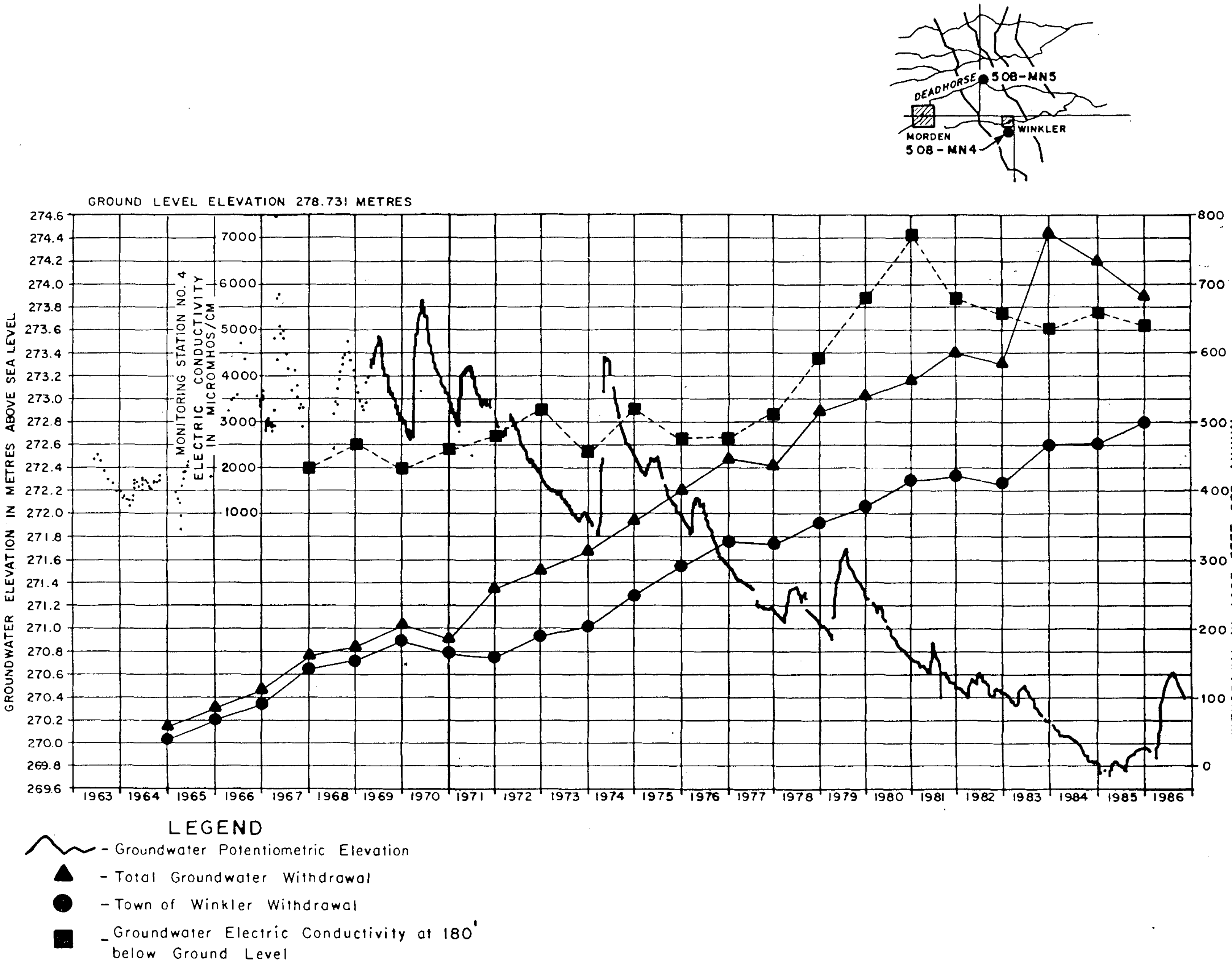
DRAWN F.B.R.	Manitoba Natural Resources	WINKLER AQUIFER
CHECKED	Water Resources	GROUNDWATER MONITORING STATIONS
PREPARED		

Manitoba
Natural Resources
Water Resources

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

WINKLER AQUIFER
HYDROGRAPHS
FOR
MONITORING STATIONS 4&5

FIGURE 13



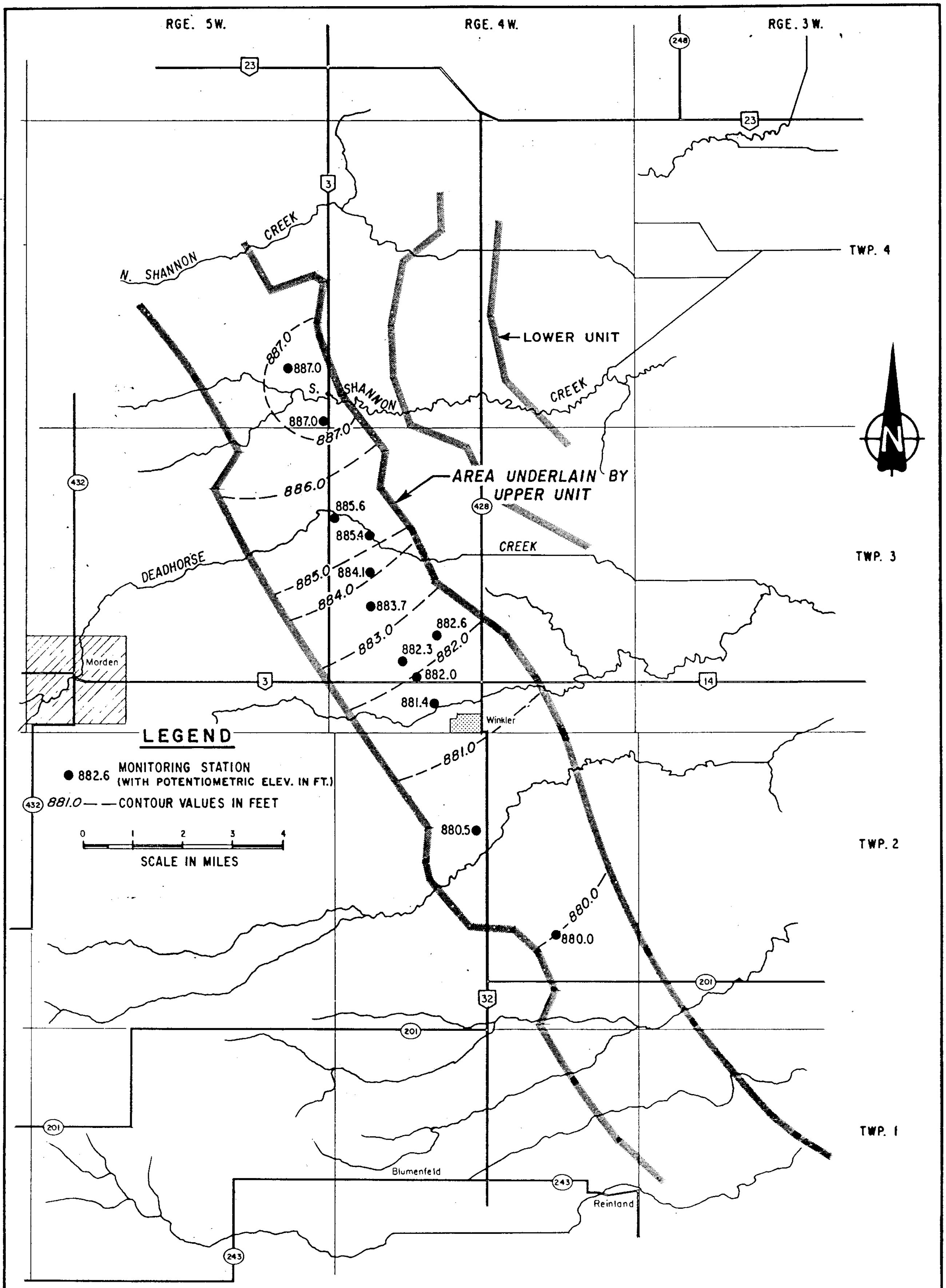


FIGURE 14

DRAWN F.B.R.	Manitoba Natural Resources Water Resources	WINKLER AQUIFER POTENTIOMETRIC SURFACE JANUARY 1986
CHECKED		
PREPARED W.H./ F.W.R.	SUBMITTED / APPROVED	SCALE AS SHOWN / DATE / SHEET OF / FILE NO. 10·1·7·1234