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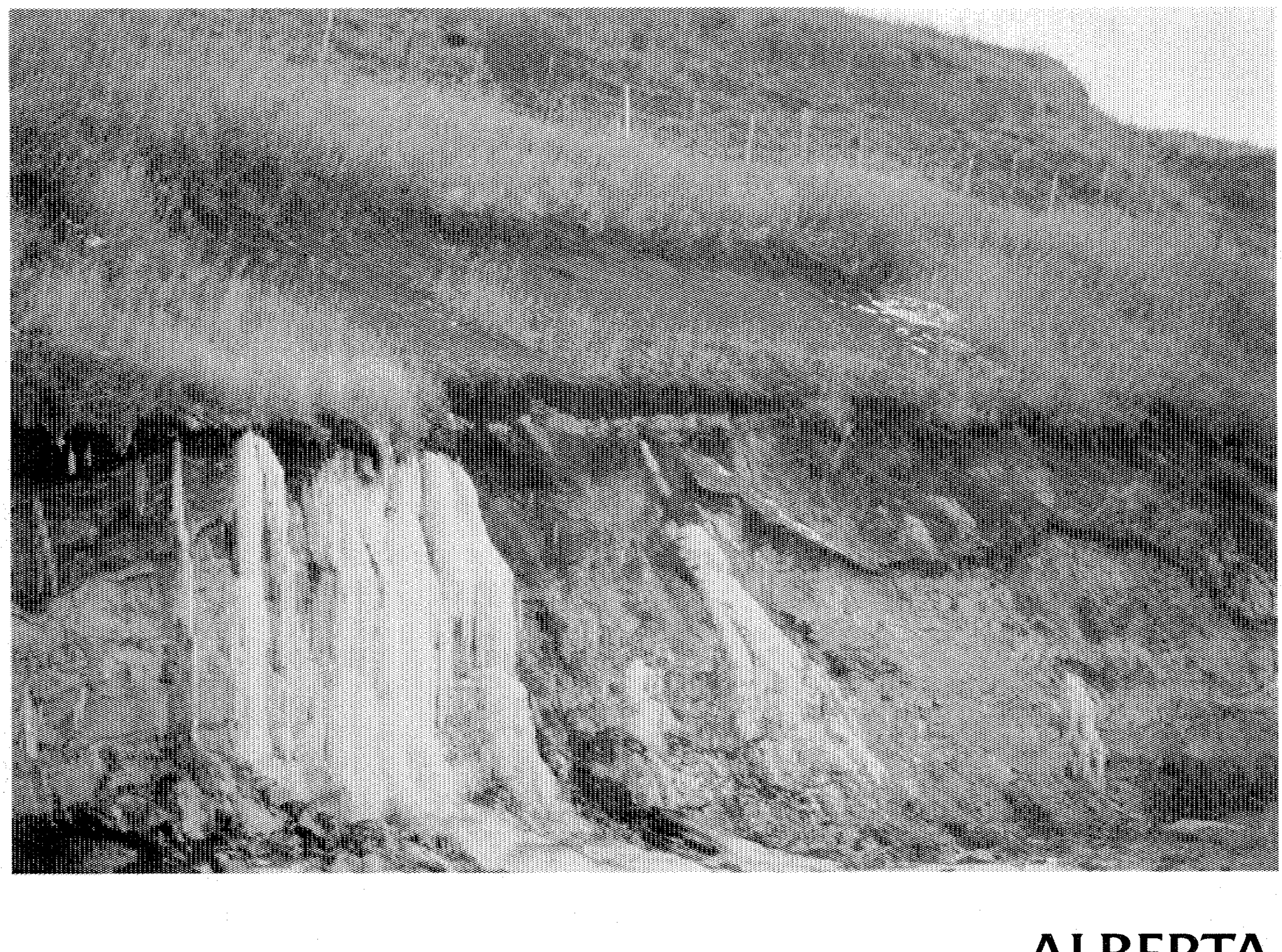
Alberta groundwater observation - well network

G.M. Gabert



ALBERTA RESEARCH COUNCIL
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Cover:
Groundwater discharge from a coal seam,
Battle River Valley
Credit: M. Trudell

TERRAIN SCIENCES DEPARTMENT, ALBERTA RESEARCH COUNCIL
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Contents

Tables

Figures

Plates

Abstract

Groundwater-level fluctuations are the result of a number of natural processes affecting addition and subtraction of water to and from the saturated zone. Within the saturated zone itself, intrinsic hydraulic processes are continuously active. There is a complex relationship between such processes, and identification of the specific effect of one process on water levels is very difficult, if not impossible. Major natural processes affecting groundwater levels include recharge and discharge of water to and from the saturated zone, respectively, and movement of water in hydrodynamic flow systems. Other important processes affecting levels are atmospheric pressure changes, transpiration, aquifer compression and aquifer dilatation.

In addition to natural processes, the activities of man affect groundwater levels. The primary activity is the withdrawal of groundwater by means of wells. Other major activities include artificial recharge, irrigation, land clearing, secondary recovery of oil, construction of reservoirs and mining.

In this report, these natural processes and major activities of man that affect groundwater levels are discussed, and illustrative examples of fluctuations are selected from hydrographs for 64 observation wells located throughout Alberta. Examples of typical hydrographs for annual water-level fluctuations unaffected by man's activities are also presented.

Examination of these hydrographs leads to a general conclusion that groundwater levels in Alberta have remained rather constant since 1959, with exceptions in local areas. The exceptions are usually caused by large-scale production (withdrawal) of groundwater from wells. Water levels are lowered during production, but recover to normal levels when production ceases. The period required to re-establish pre-production water levels ranges from a few months to many years.

Introduction

Historic summary

The Alberta groundwater observation-well network was initiated as a direct consequence of a suggestion put forth by a groundwater consultant at a provincial round-table conference on groundwater resources and development in Alberta, held in Edmonton on September 27, 1955 (Alberta Research Council, 1956). The consultant recommended that one of the responsibilities of a groundwater division should be "to establish a modest and effective water-level observation program to keep a long-term check or inventory on available groundwater." The groundwater program at the Alberta Research Council was set up on a temporary basis as part of the Geology Division in 1955. In 1956 it was firmly established as a separate division on an operational basis when a geologist was appointed to conduct investigations. In that year, the first three observation wells were established and equipped with automatic water-level recorders. Those wells, located at Drayton Valley, Leduc and Milk River, are still in operation. The groundwater observation-well network established in Alberta is truly a modest one, but data obtained have proven to be valuable references for specific and regional problems or studies concerned with groundwater levels. Responsibility for the observation-well network was transferred to the Earth Sciences Division of Alberta Environment in 1982.

Purpose and scope

The primary purpose of the provincial groundwater observation-well network has been to obtain continuous records of natural groundwater levels throughout Alberta. In addition, basic geological or hydrogeological data are sought at the time a well is established, and water samples are collected for chemical analyses and temperature determination. In practice, however, many wells included in the network were drilled in heavily pumped aquifers, or pumping wells were subsequently established near observation wells that were initially used to measure natural groundwater levels.

In order to eventually meet the purpose of the network, a long-term objective is to establish and monitor groundwater observation wells at sites representative of the various hydrogeologic environments found in Alberta. These regions characteristically have differences in physiography, climate, geology and vegetation.

Presentation of data

This publication has been prepared to:

1. inform the general public, government offices, consultants and others of the purpose of the Alberta groundwater observation-well network;
2. provide a tabulation of available basic data and hydrographs of water levels for 64 selected wells;
3. classify measured groundwater levels in order to discuss natural processes and activities of man that cause groundwater-level changes; and
4. select examples, primarily from Alberta, to illustrate the effect of natural processes and man's activities on groundwater levels.

Particulars of 64 observation wells—including names, locations, records period and completion details—are tabulated in appendix A, and hydrographs for these wells are presented in appendix C. Appendix B is a list and description of groundwater observation wells currently in the Alberta network. The hydrographs (appendix C) show the trend and range of fluctuation for groundwater levels over the period of record. Parts of hydrographs for selected wells are reproduced in the text to illustrate particular features of water-level responses to natural processes or activities of man. Photocopies of data available for particular observation wells can be obtained on request from the Earth Sciences Division, Alberta Environment.

Location of wells

Groundwater observation wells included in this report are distributed mainly in a loose network throughout the southern half of the province (figure 1). There are also three operating wells in the Peace River area of northwestern Alberta. At several locations, there are two or more wells (figure 1) located either a few metres apart at a given site or a few kilometres apart in a given locality. The majority of wells are on privately owned land, with the remainder on land owned by the Alberta Government, municipalities, cities or towns. Specific locations of all observation wells are tabulated in appendix A.

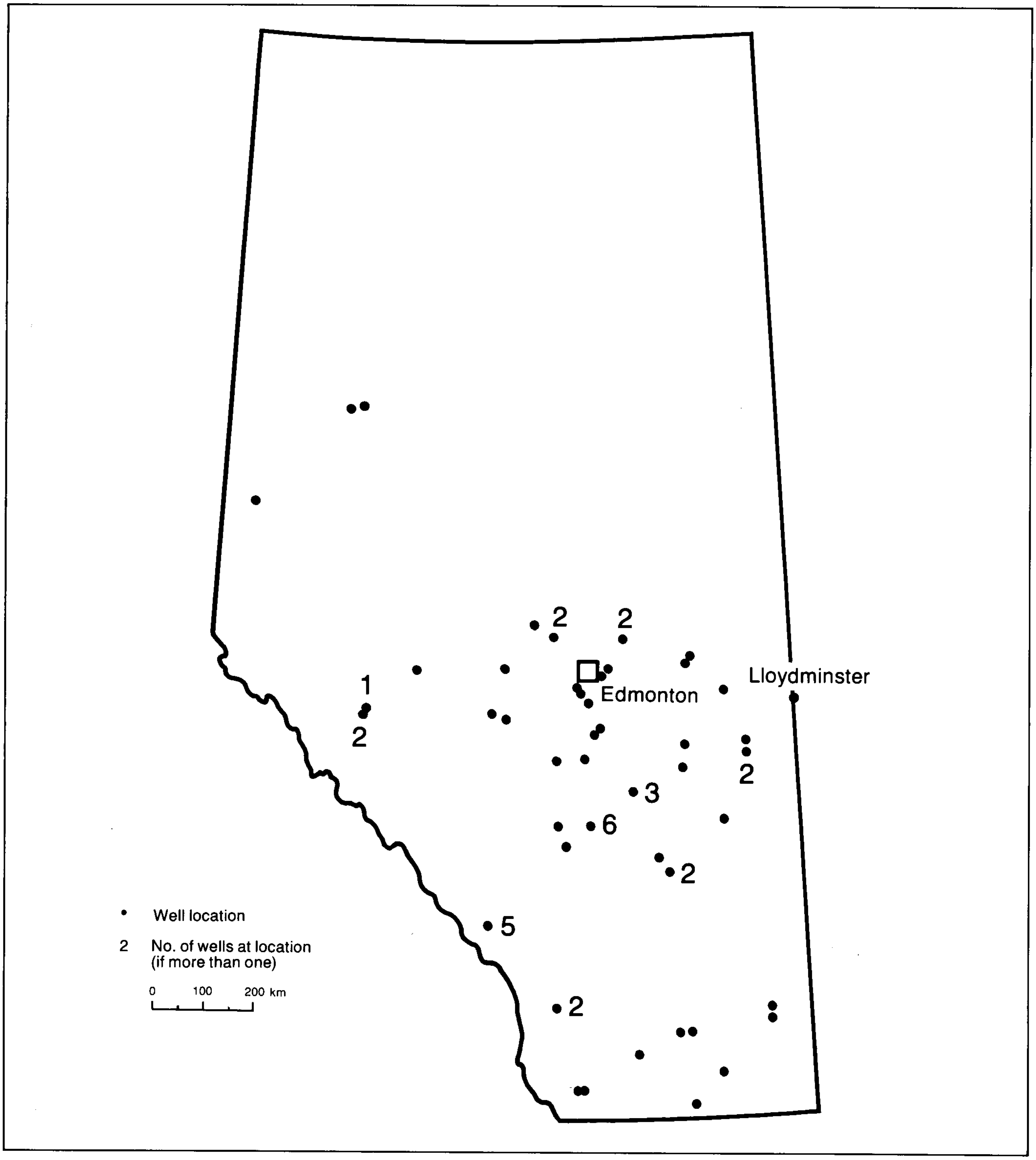


Figure 1. Locations and number of wells at groundwater observation sites in Alberta.

Methods, instrumentation and information requirements

Criteria for ideal completion of observation wells

The professional view of the author, regarding the establishment of groundwater observation-well stations in the provincial network, is that, ideally, a minimum of three observing wells should be completed at each site. They should include one water-table well and two wells to measure the hydraulic-head level of two different permeable layers—preferably the layers of highest permeabilities. The method of establishing the wells should include drilling a test hole at the site to obtain basic geological, geophysical and hydrogeological data. Geological data should include lithologic samples (from drill cuttings or cores, or both), and stratigraphic information. Borehole geophysical data should consist of an electric log, a gamma-ray log, a caliper log and a neutron log. Hydrogeological data should include results from water-level measurements for different test-hole depths, bail or pumping tests to determine hydraulic characteristics of permeable intervals (an observation and pumping well completed in the same interval are necessary to obtain the coefficient of storage), determinations of the water-table position, determinations of the thicknesses of water-bearing intervals (these can be determined accurately with the aid of a downhole flow meter), and chemical and temperature analyses of water samples. The barometric efficiency of a well should also be calculated by comparing barometric pressure changes with water-level changes in the well. The design of wells should then be based on the interpretation of the geological, geophysical and hydrogeological data.

The test hole could subsequently be used for completion of the deepest observation well. The diameter of wells with water levels as deep as 50 m should be large enough to accommodate a 10-cm outer diameter (OD) float; wells with water levels deeper than 50 m should be large enough to accommodate a 15-cm OD float. These diameters are necessary to overcome the inertia and friction in the float-and-line system. Short intervals (up to 2 m) of permeable zones should be open to the well or covered with a proper screen for the aquifer material, and the space between the casing and drill hole should be sealed. Automatic water-level recorders that give continuous records (such as Stevens Type F recorders) should be installed in each well.

The acquisition of geological, geophysical and hydrogeological data, as outlined above, should be pursued systematically at all existing observation wells for which little information is available. Information requirements and the work needed to obtain such data are listed below.

- Survey of well locations to identify coordinates
- Electric-logging or gamma-ray logging to determine lithology at the well site
- Aquifer performance test to identify various aquifer parameters
- Well performance and efficiency tests
- Measurements of the barometric efficiency of wells
- Sampling of water for chemical analyses
- Water temperature measurements
- Completion of additional wells at existing sites to determine water-table and hydraulic-head levels

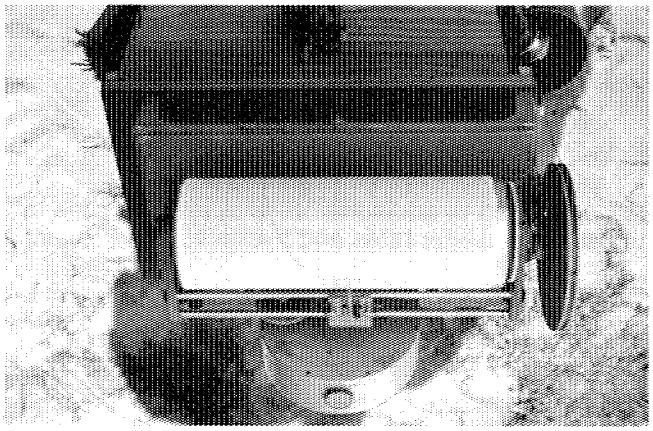
Establishment of wells in the provincial network

The major factor dictating the method of establishing groundwater observation wells in the provincial network has been a financial one. Consequently, the majority of wells were not especially designed, constructed and developed as groundwater observation wells, but were selected from either: (1) existing private wells, offered for use as observation wells, or (2) from wells completed for research and resource evaluation programs and retained as observation wells. Only 4 wells of the 64 in this report were completed specifically for the provincial monitoring network.

Stevens Type F water-level recorders

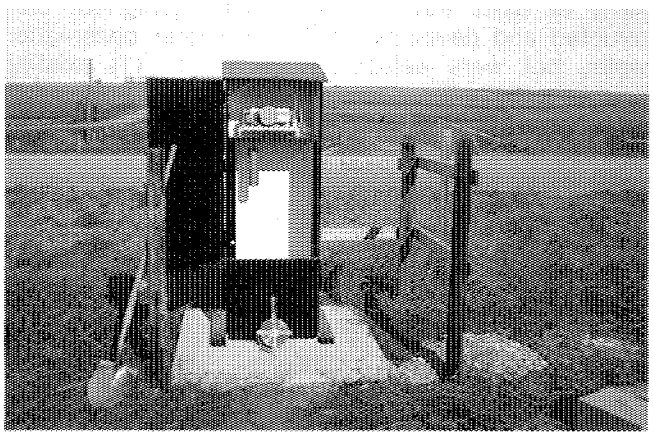
All observation wells in the network are equipped with Stevens Type F water-level recorders (plate 1). These are mechanical recorders that provide a continuous water-level measurement by means of a float that rises and falls with changing water levels. The float is attached to a pulley on the recorder by a stainless-steel line, beaded at uniform intervals and counter-weighted at the opposite end. The beads fit into matched recesses in the pulley for non-slip operation and turn the drum in exact proportions to changes in water level. The most commonly used vertical (gauge) scales are usually in ratios of 1:1 and 1:5, which means that a change equivalent to, or one-fifth the actual water-level change, respectively, will be shown on the recorder chart. Selection of suitable gears also enables the use of gauge scales of 1:2, 1:10 and 1:20. Water-level fluctuations are recorded by a capillary pen that is moved across the chart in 32 days by a weight-driven clock. The pen is filled with a special ink that flows freely at temperatures below 0°C. The smallest divisions on standard charts enable a recording accuracy of 3 mm on the vertical scale and eight hours on the horizontal (time) scale.

An example of the protective housing and enclosures for recorders is shown in plates 2 and 3. In practice, manual measurements for correlation purposes are taken at least three times a year during routine inspection of installations. Additional measurements and inspections are required when recorders malfunction. An electric sounder or chalked steel tape (plate 4), having an accuracy of 3 mm, is used to obtain water-level measurements manually. Charts are changed once per month by staff, paid



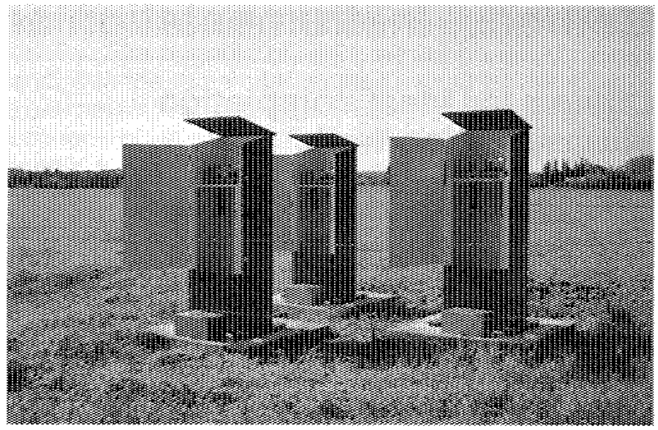
D. WITHERS

Plate 1. Stevens Type F water-level recorder.



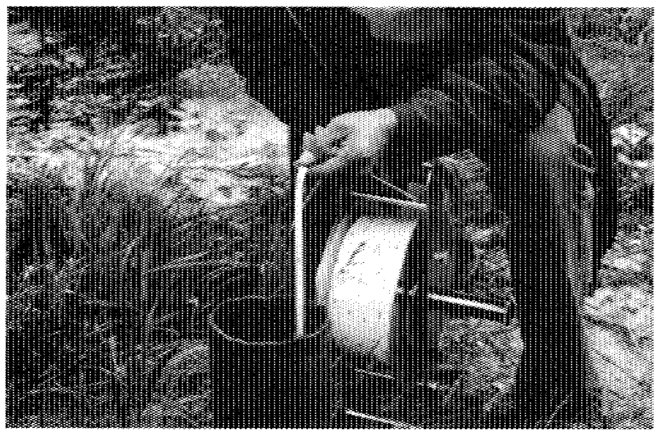
D. WITHERS

Plate 2. Protective housing for recorders.



D. WITHERS

Plate 3. Multiple recorder installation.



D. WITHERS

Plate 4. Electrical tape water-level measuring device.

observers or voluntary observers. Observers also inspect recorders each month when charts are changed.

The main advantages of the Stevens Type F recorder for use in Alberta are:

- The capital cost of the recording unit is acceptable.
- The mechanism is simple in construction and operation.
- The recorder does not require an external power source.
- Excellent versatility of vertical (gauge) scales is provided.
- A good selection of horizontal (time) scales is available.
- The once-per-month frequency of chart change is suitable for the observation-well network.
- Maintenance costs are acceptable.

The main disadvantages, in practice, are:

- Clock mechanisms tend to stop or function poorly at temperatures below -30°C.
- Wells with water levels higher than 50 m below surface require a well diameter large enough to accommodate a 15-cm OD float to obtain satisfactory measurements of water level.
- Frequent inspection of the recorder system is necessary to ensure continuous operation.

The capital cost, based on 1984 prices, of installing one automatic water-level recorder (excepting the cost of the well) is as follows:

Recorder	$1500.00
Protective housing	225.00
Concrete pad and installation	100.00
Enclosure	50.00
Total capital cost	$1875.00

Annual operation cost, based on 1985 prices, for a network of 64 observation wells is as follows:

Charts, ink, clock repair	$900.00
Staff salaries and expenses	27 600.00
Observer salaries and expenses	1 600.00
Vehicle cost	10 000.00
Total annual operation cost	$40 100.00

Classification and sources of groundwater

Definitions

All the water that exists below the surface of the solid earth is called **subsurface water** to distinguish it from surface water and atmospheric water (Meinzer, 1923).

Furthermore, there are several divisions and subdivisions of subsurface water (table 1).

The open spaces within rocks of the earth's crust, below a certain depth, are generally filled with water. Rocks below such a depth are said to be in the **saturated zone**, and water occurring in this zone is known as **groundwater** or **phreatic water** (Meinzer, 1923). Water in the saturated zone is under hydrostatic pressure that is greater than normal atmospheric pressure. The upper surface of the saturated zone is known as the **water table**, which is more exactly defined as the surface in unconfined material along which the hydrostatic pressure is equal to atmospheric pressure (Davis and DeWiest, 1966). The interval from the land surface to the water table is not saturated, and rocks in this interval are said to be in the **unsaturated zone** (Bennett et al., 1972). Water in this zone is under less than atmospheric pressure.

The unsaturated zone is divided, from the land surface downward, into three subzones: 1) a soil-water subzone, 2) an intermediate subzone, and 3) the capillary-fringe subzone. Soil-water is essentially that water near enough to the land surface to be available to the roots of plants. Water in the intermediate subzone, which is between the soil-water subzone and the capillary-fringe subzone, generally moves downward under the force of gravity, eventually becoming capillary water or groundwater. Capillary water is held by capillarity in the interstices of rock located immediately above the saturated zone. Water in the lower part of the capillary-fringe subzone is continuous with the water in the saturated zone, but strictly speaking, is at less than atmospheric pressure.

The lower limit of the saturated zone is theoretically accepted by hydrogeologists as a certain great depth below surface where open spaces in rocks are not present, primarily because of the great increase in pressure caused by the weight of overlying geologic deposits. It is known that the size of interstices in rocks decreases with increasing depth. Hitchon (1968) has shown that the average porosity of strata in the plains region of the western Canada sedimentary basin decreases with age and with depth of burial of the strata, both within specific lithologic types and for the total basin. He computed average porosities of 26.3, 17.3 and 6.8 percent for Cenozoic, Mesozoic and Paleozoic stratigraphic units, respectively. The western Canada sedimentary basin includes most of Alberta, and strata range in thickness from 0 m in the northeast corner of the province to over 5000 m in western Alberta, adjacent to the folded strata of the Foothills Belt. Groundwater is known to occur in strata ranging in age from Late Cretaceous to pre-Late Devonian (Granite Wash) and to depths of nearly 3500 m in the basin (Hitchon and Friedman, 1969). Groundwater below 600 m normally contains a total dissolved solids content of greater than 10 000 mg/L. The probable maximum depth interval at which potable groundwater with a total dissolved solids content of 1500 mg/L or less occurs in the plains area of Alberta is from 300 to 450 m (Meyboom, 1960; Tokarsky, 1971; Borneuf, 1974). The majority of potable water supplies in Alberta are developed from aquifers less than 150 m deep. Actual statistics are not available for Canada, but would probably be similar to figures for the United States that show that only 2.1 percent of water wells drilled in 1966 were greater than 150 m deep (Todd, 1970).

Table 1. Classification of subsurface water

	Main Division	Subdivision	Classification of Water
SUBSURFACE	Unsaturated zone	Soil-water subzone	Soil-water
		Intermediate subzone	Intermediate water
		Capillary-fringe subzone	Capillary water
	— Water table —		
WATER	Saturated zone		Groundwater

Sources of groundwater

Precipitation, mainly in the form of rain or snow, is the ultimate source of virtually all groundwater. The phenomenon that the long-term average contour of the water table (top of the saturated zone), on a large scale, is a subdued replica of the topography indicates that precipitation is the main source of water for recharge. Snowmelt and rainfall result in water that infiltrates soil layers and moves downward through the unsaturated zone to the top of the saturated zone (water table) or indirectly reaches the saturated zone as influent seepage from lakes, rivers and man-made storage. A small part of groundwater (connate water) is water that has been trapped in sedimentary and other rocks since the time of their origin, and an even smaller quantity is added to the saturated zone from deep within the earth's crust. The latter source (juvenile water) has either been imprisoned in the earth's interior since its formation, or is of chemical origin.

Classification and accuracy of measured water levels

Water levels measured in observation wells in Alberta can be classified as either water-table levels or hydraulic-head levels. The water-table level is the level in unconfined material, along which the hydraulic pressure is equal to atmospheric pressure. The hydraulic-head level is the height above a standard datum (usually sea level) of the surface of a column of water than can be supported by the hydraulic pressure at a given point. In terms of height above mean sea level, the hydraulic-head level (H_i) at a point (i) in the saturated zone is the sum of the elevation head (Z_i) and the pressure head ($P_i/\rho_i g$); that is,

$$H_i = \frac{P_i}{\varrho_i g} + Z_i \quad \text{(in units of length)}$$

where

- i = any point in the saturated zone
- H_i = height of hydraulic-head level, above mean sea level
- Z_i = elevation of i
- P_i = pressure at i
- ϱ_i = density of water at i
- g = gravitational acceleration

Figure 2 is a diagramatic representation of the equation components. The water table can be considered a particular hydraulic-head level with the pressure head ($P_i/\varrho_i g$) equal to zero. Water levels for groundwater observation wells in Alberta are classified in appendix A. All water levels are recorded with reference to the depth from the top of casing, which is usually less than 0.5 m above ground surface.

The accuracy of measured groundwater levels cannot be stated objectively, because sufficient data are not available presently to analyze the relationships between permeability, response time and well type.

Wells designed to measure water-table levels usually are completed 1 or 2 m into the saturated zone. Ideally, the hydraulic pressure of this water level might not be exactly equal to atmospheric pressure, but the water level is considered to closely approximate the water-table level.

Wells designed to measure representative hydraulic-head levels are completed in the most permeable intervals because permeability is the main factor influencing response time for a given well diameter. Furthermore, hydraulic-head levels measured in observation wells are primarily that of the interval of highest permeability open to the well and are probably little influenced by exposed intervals of much lower permeabilities.

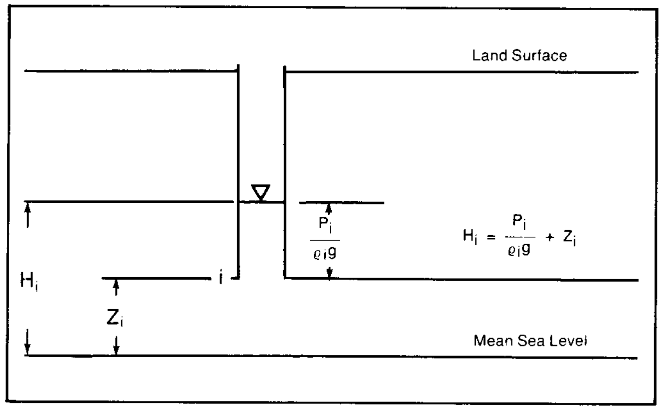


Figure 2. Definition of hydraulic-head level (H_i).

Natural processes causing groundwater-level fluctuations

Water-level fluctuations viewed in respect of the hydrologic system

Natural groundwater levels are either rising, falling, or remaining constant, in response to the net effect of hydrologic processes active in the atmosphere, at the surface of the earth, in the unsaturated zone and in the saturated zone itself. These hydrologic processes are many, and are distributed within the major components of the hydrologic system, including precipitation, runoff, infiltration, groundwater movement and evapotranspiration. Furthermore, these processes are in a state of dynamic equilibrium, which is evidenced by the phenomenon that water-table fluctuations are kept within relatively narrow bounds. This equilibrium, in respect of the saturated zone, is known as the groundwater balance and can be expressed by a simple form of the general hydraulic equation:

$$Ws = \text{Inflow} - \text{outflow}$$

where Ws equals the change in groundwater storage. It is evident that, if inflow into a groundwater system exactly equals outflow from the system, storage will remain constant. A rise in water-table level is usually interpreted as meaning an increase in storage, and a fall in water-table level normally is considered to indicate a decrease in storage. Correspondingly, a rise or fall in piezometric level is interpreted as meaning an increase or decrease, respectively, in storage of an aquifer. Inflow to the saturated zone is called recharge, and outflow is called discharge. By substituting these two terms into the hydraulic equation, the groundwater balance equation is written:

$$Ws = Q_r - Q_d,$$

where Q_r is groundwater recharge and Q_d is groundwater discharge (Ward, 1975).

Water-level fluctuations viewed as a result of groundwater movement in hydrodynamic flow systems

Hydrogeological research emphasis in the 1960s and early 1970s was placed on the study of regional groundwater flow systems. The main method of study has been to construct two-dimensional, vertical flownets, perpendicular to maximum gradients on the water-table surface. Flownets so constructed provide an excellent framework to identify areas of recharge and discharge; that is, areas where the direction of groundwater flow is away from or towards the water table, respectively (Freeze and Witherspoon, 1967). Groundwater-level fluctuations can then be viewed, with better understanding as the result of groundwater movement in hydrodynamic flow systems.

Tóth (1963) presented a theoretical model that accounted for the effect of local topographic relief on the water-table configuration. The porous medium was assumed to be homogeneous and isotropic. The flow patterns that he obtained demonstrated the possible occurrence of three distinctly different types of flow systems in a composite basin: local, intermediate and regional. The configuration of flow systems and the distribution of recharge and discharge areas along the upper surface of the model are shown in figure 3.

Flownets constructed from water-table and hydraulic-head measurements in the field verify the theoretical models. Figures 4 and 5 show cross-sections of groundwater flow patterns and the surface distribution of recharge and discharge areas drawn from water levels measured in observation wells. Figure 4a shows a flownet for a local flow system near Rocky Mountain House (Gabert, 1984) in the western Alberta plains, and figure 4b shows the groundwater flow pattern along a profile through Horseshoe Lake near Metiskow (Wallick, 1981), in the east-central Alberta plains. Figure 5 shows the pattern of groundwater flow in the Arm River Valley, Saskatchewan (Meyboom et al., 1966).

The change of groundwater levels and their relationship to groundwater flow systems in Alberta can be more easily comprehended if one considers that the entire ground surface is frozen during the winter months; that is, no water is being added to the saturated zone. The expected water-level changes, then, would result from the movement of groundwater from recharge areas to discharge areas. Water levels would fall in recharge areas and would rise in discharge areas. Water levels at locations where flow is lateral (transition zones) would remain nearly constant. Many observed groundwater levels in Alberta, in both recharge and discharge areas, however, typically display a decline during winter months. This response generally would be expected in recharge areas, but not in discharge areas. The primary reason for the decline in water levels in discharge areas is that actual discharge of groundwater at the surface can be observed at many locations during the winter months. This discharge appears to be more concentrated than during summer months, but is evident throughout Alberta in classic discharge areas, whether local, intermediate or regional in scale. Much of the discharge probably occurs below ice-covered lakes and rivers. Plates 5, 6 and 7 show mid-winter discharge of groundwater at three different locations in Alberta.

Water-level fluctuations viewed as the net result of groundwater recharge and discharge processes active in the unsaturated and saturated zones

Todd (1959) stated that recharge is the main factor governing groundwater-level changes and that the magnitude of fluctuations depends on the quantities of water recharged and discharged. The definitions of recharge and discharge processes used in this paper

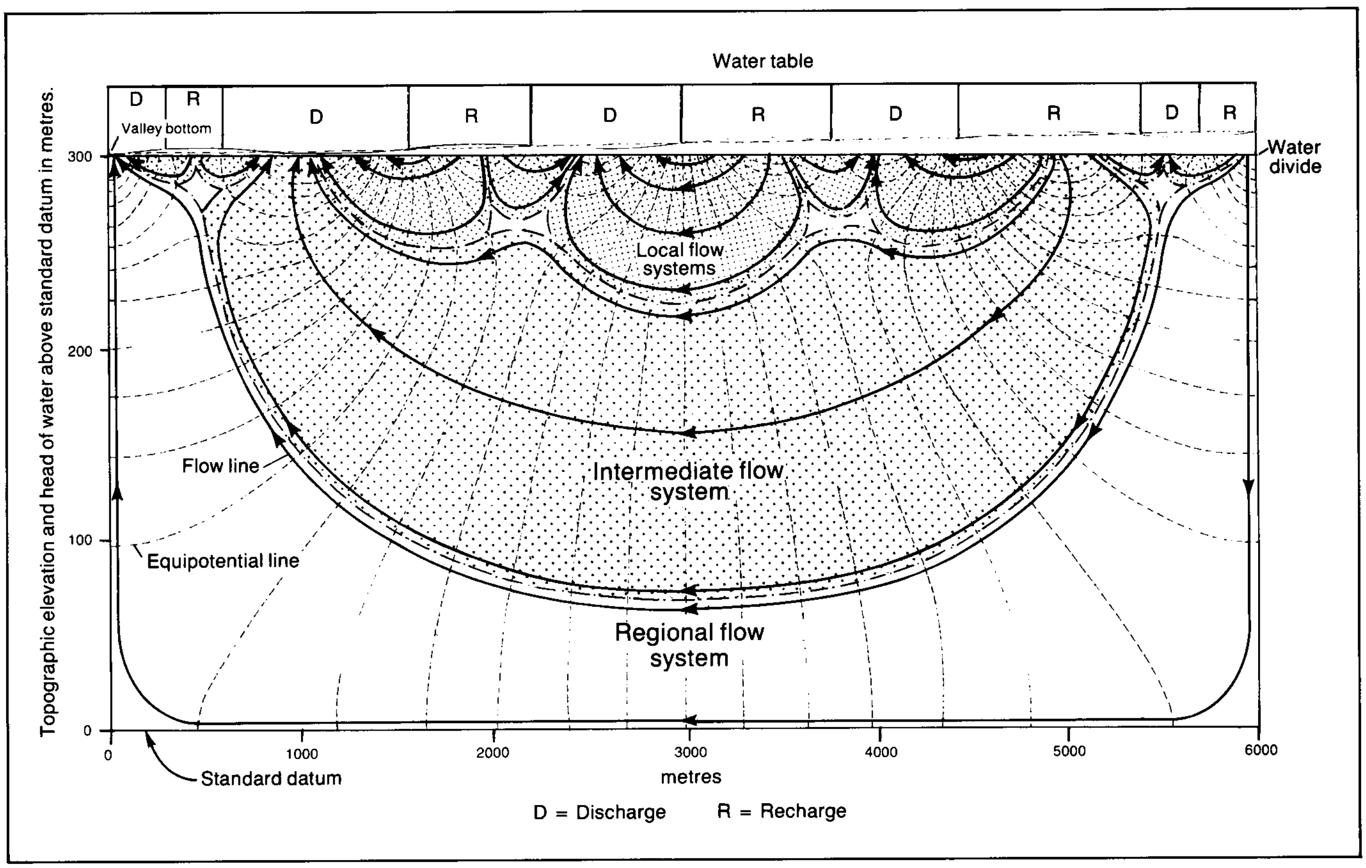


Figure 3. Surface distribution of recharge and discharge areas for three orders of flow systems in a homogenous and isotropic medium (after Tóth, 1963).

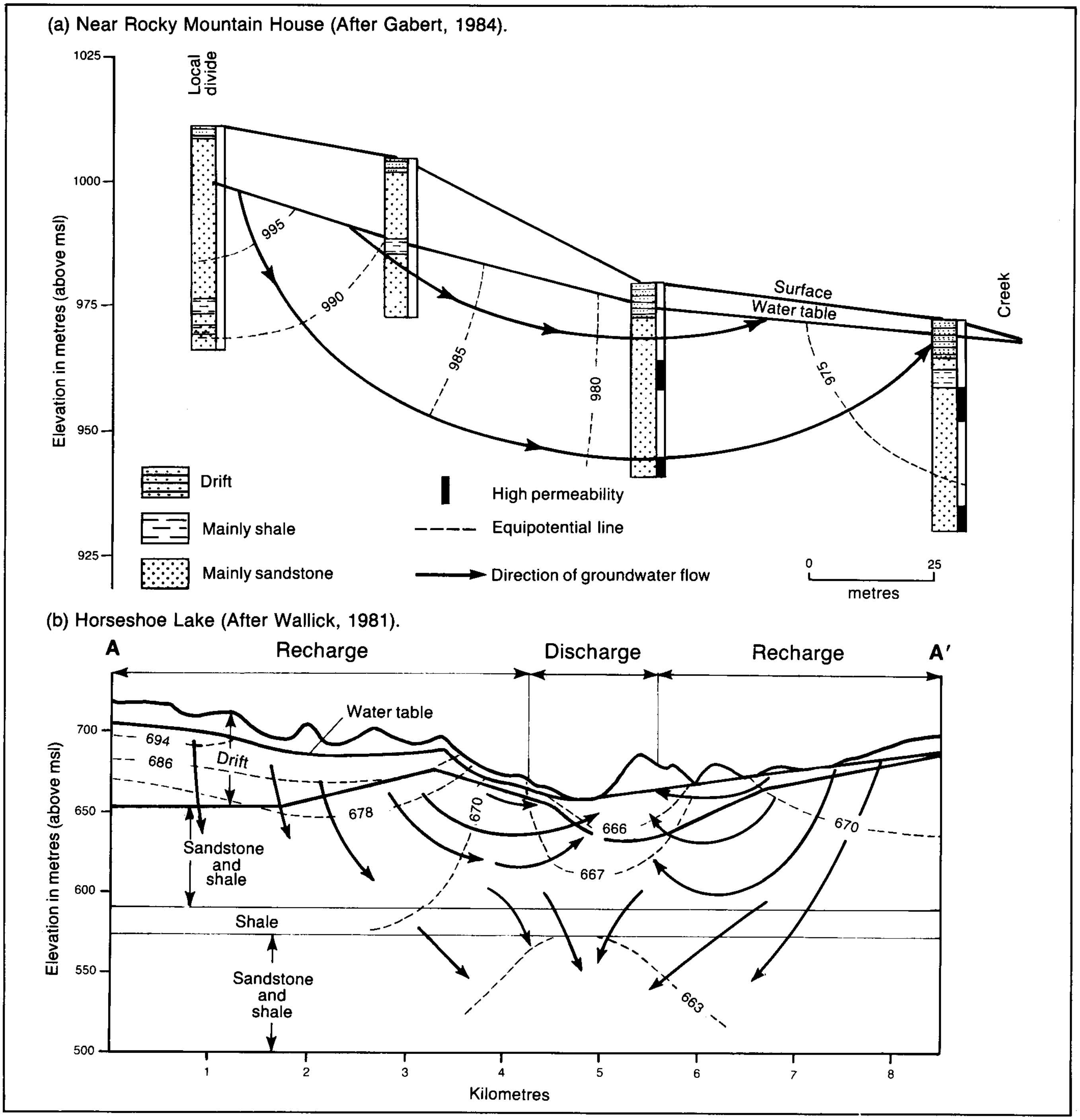


Figure 4. Groundwater-flow patterns in Alberta based on actual hydraulic head measurements.

have been presented by Freeze (1969a), who defined these processes on the basis that groundwater flow in the saturated zone (that is, within flow systems) is continuous with the flow of water in the unsaturated zone. He stated that the unsaturated flow processes of infiltration and evaporation are in physical and mathematical continuity with the parallel processes of recharge and discharge. Definitions were stated as follows:

Infiltration is the entry of water into the soil at the ground surface, together with the associated downward flow.

Evaporation is the removal of water from the soil at the ground surface, together with the associated upward flow.

Recharge is the entry of water into the saturated zone across the water-table surface, together with the associated flow away from the water table within the saturated zone.

Discharge is the removal of water from the saturated zone across the water-table surface, together with the associated flow toward the water table within the saturated zone.

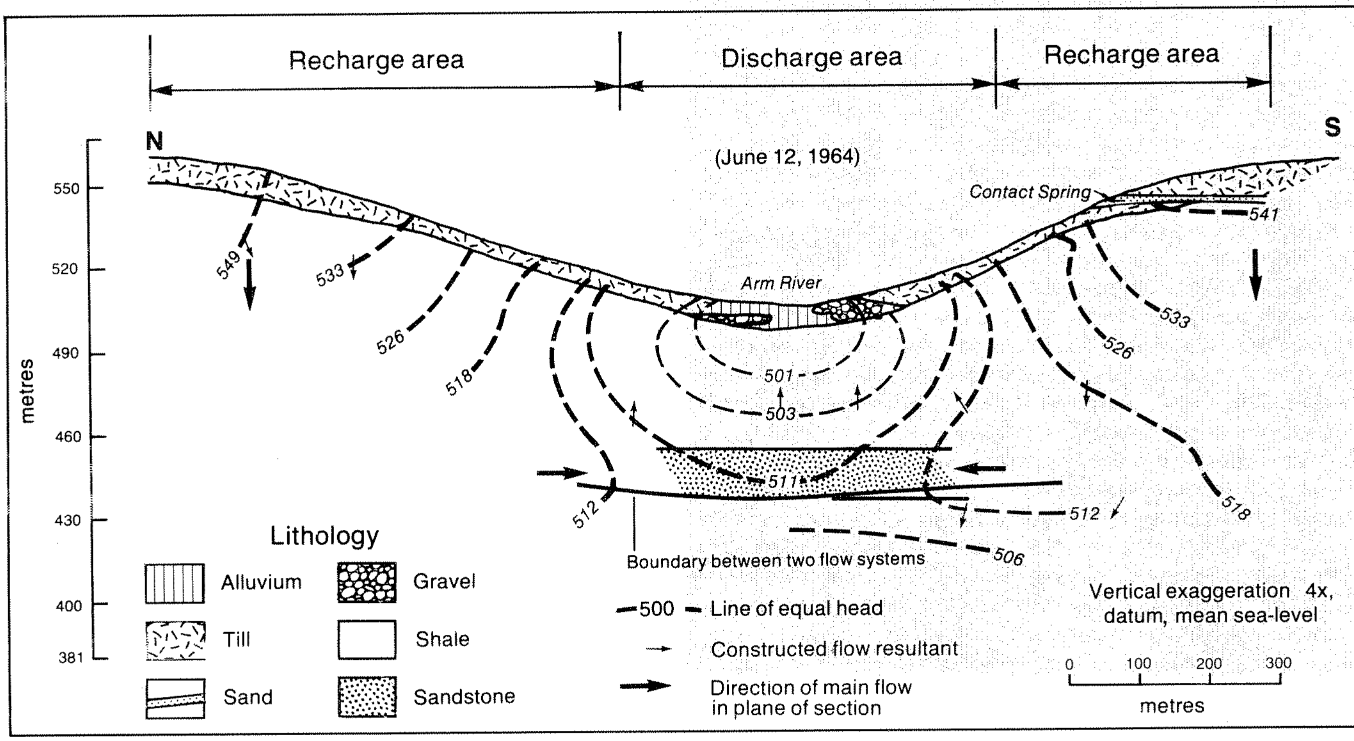


Figure 5. Groundwater-flow pattern, Arm River Valley, Saskatchewan. (After Meyboom et al., 1966).

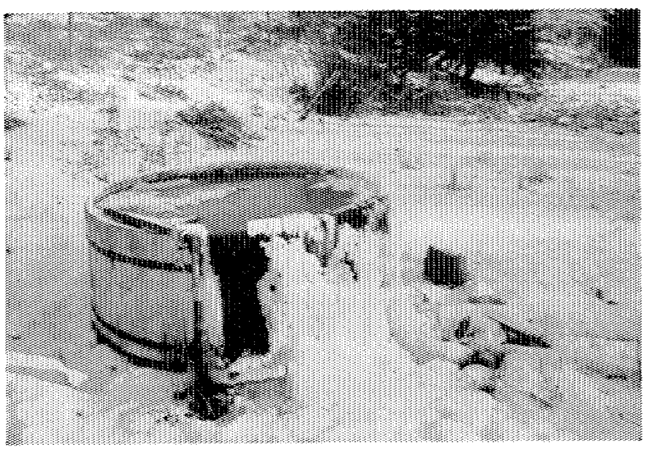


Plate 5. Capture of groundwater from spring discharge, Pigeon Lake.

In a series of papers, Freeze (1967, 1969a, 1969b) developed the concept of the continuity between groundwater-flow systems and flow in the unsaturated zone, and investigated specifically the mechanism of groundwater recharge and discharge. His method of research combined the use of a mathematical model, laboratory experiments and field measurements, and showed correlative agreement among these three techniques.

In accordance with the concept of recharge and discharge proposed by Freeze (1969a, 1969b), water-table fluctuations result when the rate of groundwater recharge or discharge is not matched by the rate of infiltration or evaporation in the unsaturated zone. That is, when the recharge rate is less than the rate of infiltration supplying water to the top of the saturated zone, the water-table level will rise; when the recharge

Plate 6. Groundwater discharge into the Bow River.

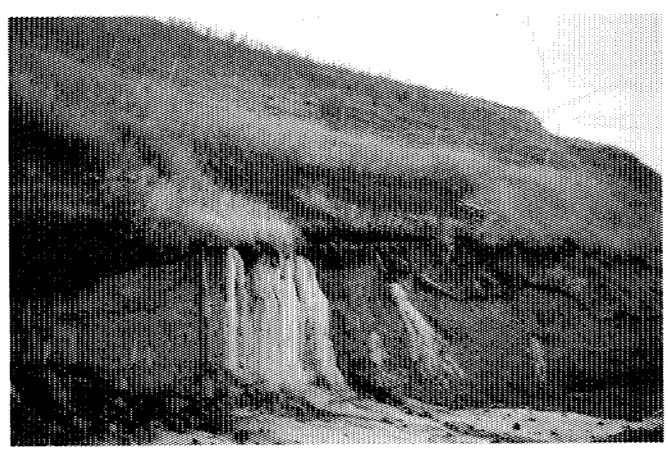


Plate 7. Groundwater discharge from a coal seam, Battle River Valley.

rate is equal to the infiltration rate, the water-table level will remain constant; and when the recharge rate exceeds the rate of infiltration to the saturated zone, the water-table level will decline. Congruously, when the discharge rate is less than the rate of evaporation to the saturated zone, the water-table level will decline; when the two rates are equal, the level will remain constant; and when the discharge rate exceeds the evaporation rate, the water-table level will rise.

The direction of water flow in the saturated zone, with respect to the water table, is of the utmost importance when considering recharge to the saturated zone. All water flowing down to the top of the saturated zone in a recharge area can potentially enter and flow through a groundwater flow system. However, water flowing down to the water table in a discharge area is added to the saturated zone and will cause a rise in the water-table level. Recharge can therefore take place in major discharge areas, however, because the difference in the rate at which water reaches the water table will cause local mounding on the water table and consequently the development of small local flow systems. As the flow of water reaching the saturated

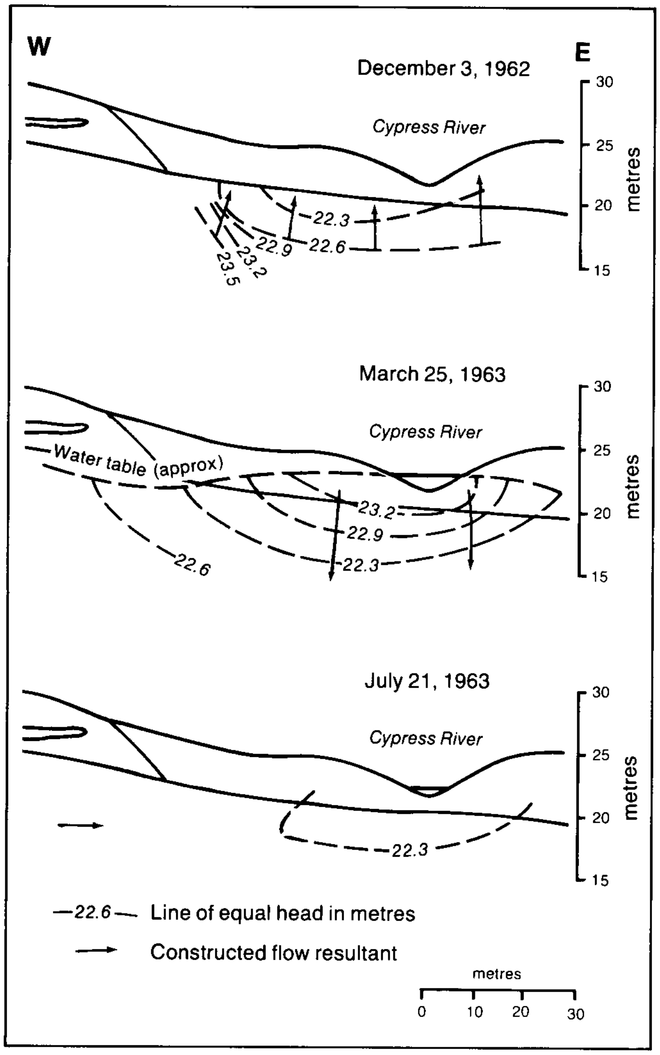


Figure 6. Patterns of groundwater flow along the Cypress River, Manitoba. (After Meyboom, 1966).

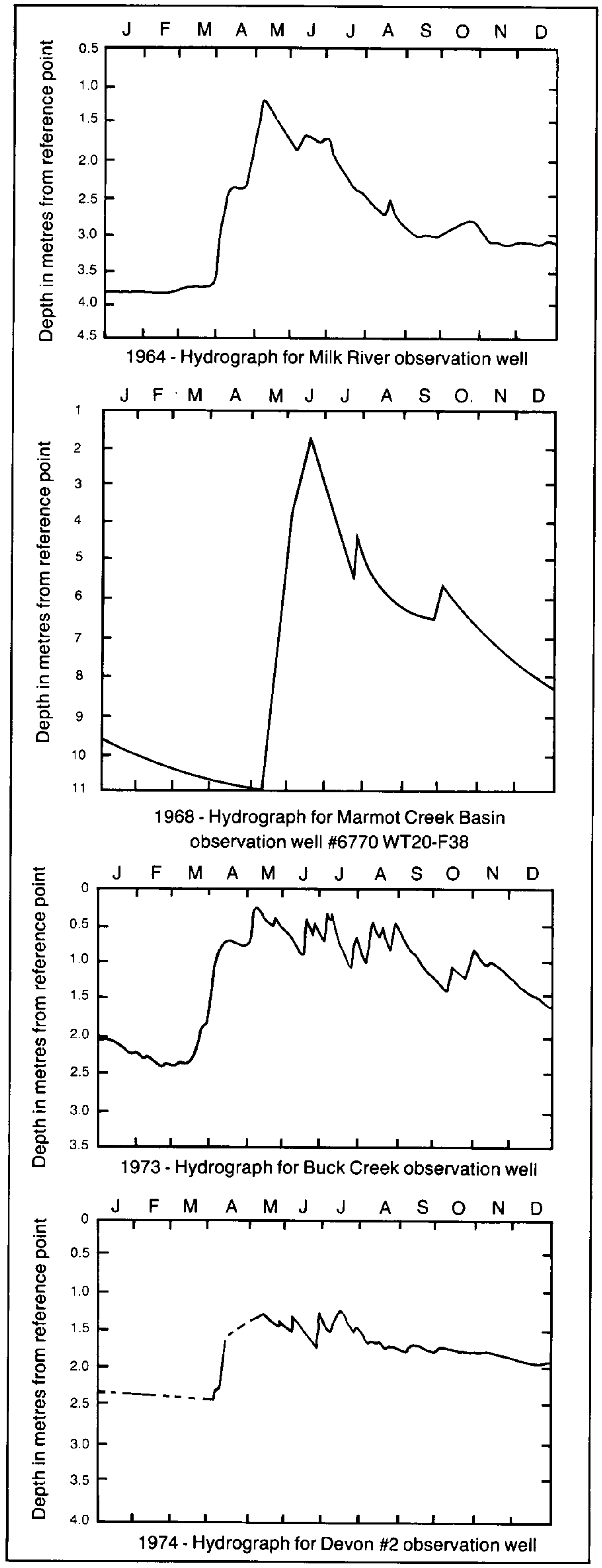


Figure 7. Typical annual hydrographs of water-table fluctuations.

zone in major discharge areas diminishes, these local systems will dissipate rapidly due to the dominating effect of larger flow systems. Meyboom et al. (1966) presented patterns of groundwater flow along the Cypress River, Manitoba (figure 6) that illustrate this phenomenon.

A typical annual hydrograph for water-table level in Alberta shows a marked rise in the springtime from snowmelt recharging the saturated zone followed by a recession curve interrupted by minor rises due to recharge from long-duration, low-intensity rainfalls during the late spring, summer and fall. Selected examples of annual hydrographs of water-table levels for observation wells located at Buck Creek, Devon, Marmot Basin and Milk River are shown in figure 7. The rapid response of water-table level rise due to the infiltration of precipitation in an area of stable dune sand was documented by Gabert (1968). The hydrograph (figure 8) of water level in an observation well showed a rapid rise of about 0.13 m as a result of high-intensity summer showers on each of two days in June, 1967. The rise in water level on June 17 was observed by Gabert (1968) to have begun in less than two hours after rainfall started.

Ryckborst and Gabert (1978) measured water levels in mainly large-diameter wells in the Edmonton region at monthly intervals during a period from 1964 to 1968. The water levels were considered to be representative of water-table levels (figure 9). Analysis of the oscillations of groundwater levels due to recharge from snowmelt in surficial deposits and bedrock sediments with very low permeability showed that the phase lag and amplitude attenuation observed is the result of vertical unsaturated groundwater diffusion. This phenomenon is illustrated for wells completed in the surficial deposits (figure 9a) and in bedrock deposits (figure 9b). Calculations showed that water infiltrates through the unsaturated surficial deposits with velocities ranging from 17 to 42 mm day^{-1} and through the bedrock with an average velocity of 63 mm day^{-1}. All wells showed harmonic fluctuations with a period of one year and phase shifts up to several months where the groundwater table is deep.

Other natural processes causing water-level fluctuations

Atmospheric pressure changes

Changes in atmospheric pressure have no effect on water-table levels, but do produce sizeable fluctuations of water levels in wells completed in confined aquifers. The net result of a change in pressure is transmitted directly to the water column, resulting in a rise or fall in water level as atmospheric pressure decreases or increases, respectively. Examples of the relationship of corresponding changes in atmospheric pressure and in water levels in wells completed in confined aquifers are shown in figure 10. The ratio of a change in water level in a well to the change in atmospheric pressure is known as the barometric efficiency of a well.

Transpiration

Transpiration is the evaporation of water absorbed by plants. Meyboom (1966) showed diurnal water-table fluctuations due to transpiration by phreatophytic vegetation. The water-table fluctuations below willows in the Arm River Valley in Saskatchewan during the summer are illustrated in figure 11. The water table declines during the day when the rate of evapotranspiration exceeds the rate of discharge and recovers at night when the rate of discharge is greater. These fluctuations are usually minor in nature, but over a long period of time, transpiration can account for significant declines in water-table levels in the zone of root development.

Aquifer compression and dilatation

Oceanic tides, earth tides and seismic waves resulting from earthquakes are three well-known natural phenomena that cause aquifer compression and

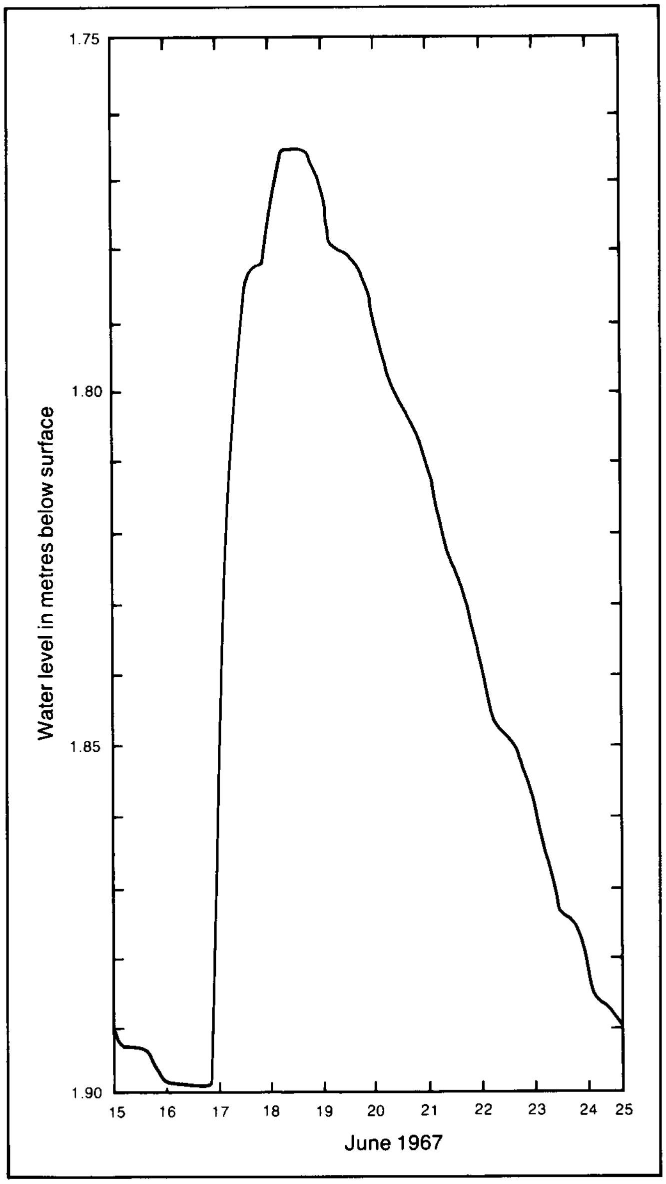


Figure 8. Response of water table to rainfall event.

dilatation. The effect of these phenomena on aquifers is indicated by water-level fluctuations in wells.

The gravitational attraction between the earth, moon and sun, and the centrifugal force due to the earth's rotation cause rhythmic deformations of the earth, which produces not only ocean tides, but also earth tides. Earth tides cause alternate expansion and contraction of the pore volume of the solid earth, which is indicated by water-level fluctuations in observation wells. Meneley (1970) observed water-level fluctuations in observation wells in Saskatchewan that he attributed to the effects of earth tides. Carr (1971) analyzed tidal fluctuations in wells in a confined aquifer near the coast in Prince Edward Island where the tide is mixed but mainly semidiurnal. A portion of a hydrograph from one observation well is shown in figure 12.

Water-level fluctuations caused by earthquakes have been recorded throughout the world. These fluc-

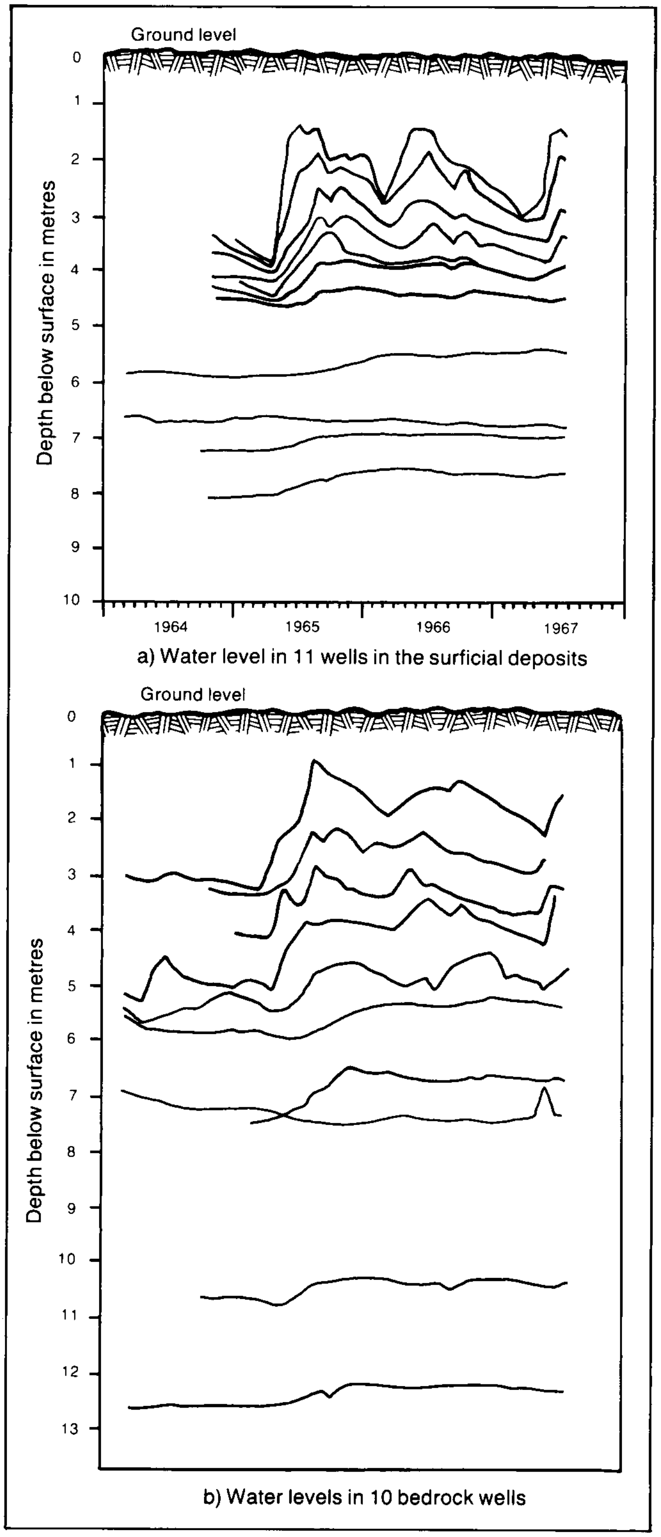


Figure 9. Oscillations of water-table levels due to recharge from snowmelt in the Edmonton area, Alberta. (After Ryckborst and Gabert 1978).

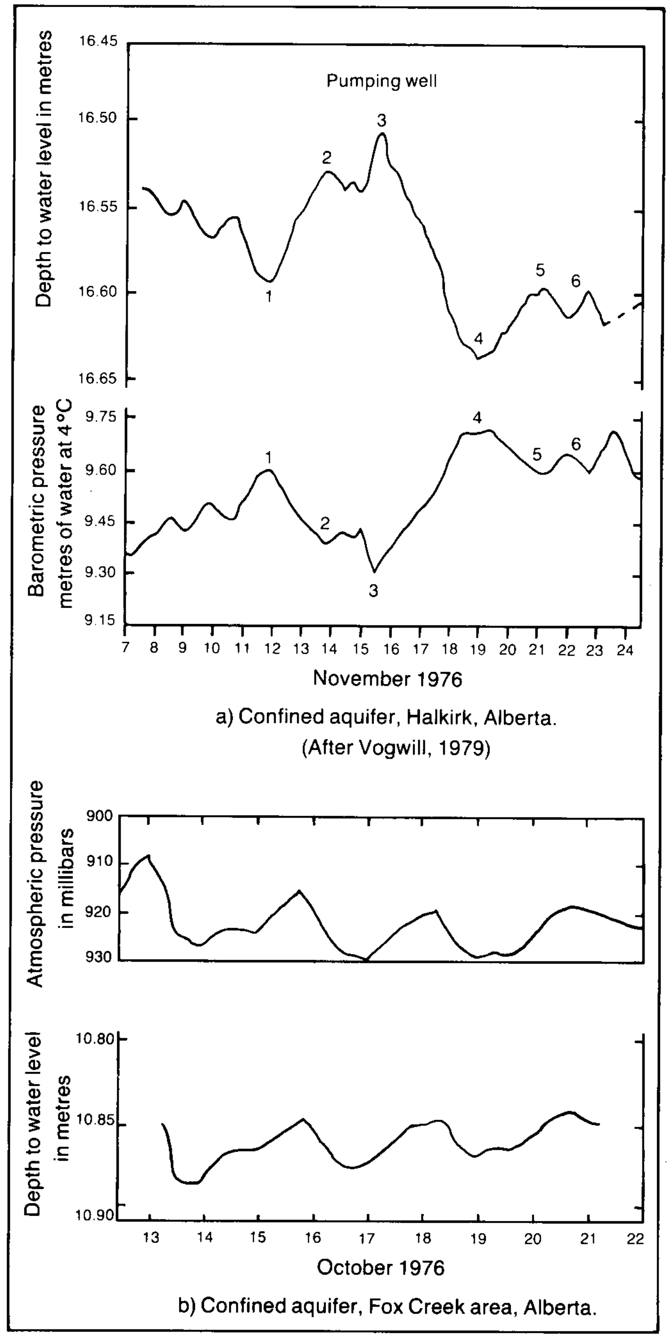


Figure 10. Groundwater level changes caused by corresponding changes in atmospheric pressure.

tuations have been observed in both wells and in surface water bodies. Wells completed in confined aquifers usually show water-level fluctuations as a result of earthquakes, but fluctuations are not common in wells completed in unconfined or water-table aquifers. Rayleigh waves (R-waves) or the surface seismic waves are the ones most likely to affect water levels. Basalts and limestone beds seem the most favorable geologic units for large fluctuations, but to date in Alberta, where observation wells are completed in surficial deposits or in continental sandstone and shale sequences, the largest recorded fluctuation occurred in a well completed in a thick sandstone unit. Continuity of the trend of a hydrograph before and after the disturbance and the equity of the fluctuation above and below the trend line are typical for fluctuations caused by distant earthquakes. Residual water-level changes can be interpreted as indications of permanent rearrangement of local rock material. Groundwater-level fluctuations caused by the Prince William Sound, Alaska earthquake of March 1964 were studied by Gabert (1965). Figure 13 shows the hydrograph for the observation well at Ponoka. This well is completed in a confined, thick, sandstone aquifer and the earthquake-induced groundwater-level fluctuation on March 27 was greater than 1.5 m in amplitude.

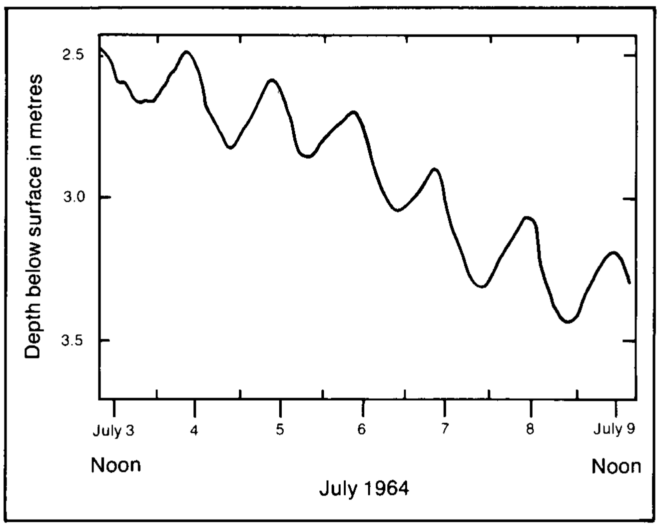


Figure 11. Diurnal water-table changes due to transpiration by willows. (After Meyboom, 1966)

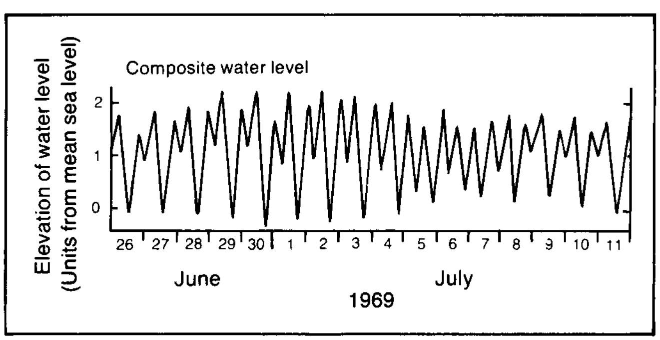


Figure 12. Groundwater-level changes in a confined aquifer caused by ocean tides, Prince Edward Island (after Carr, 1971).

Figure 14 shows the water level in a well near Elnora, Alberta. The water level rose 0.2 m as a result of the earthquake and gradually dissipated. This in-

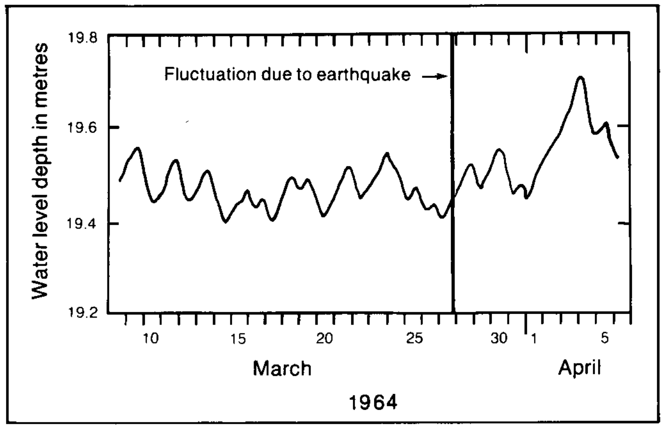


Figure 13. Groundwater-level response caused by a distant earthquake, Ponoka, Alberta (after Gabert, 1965).

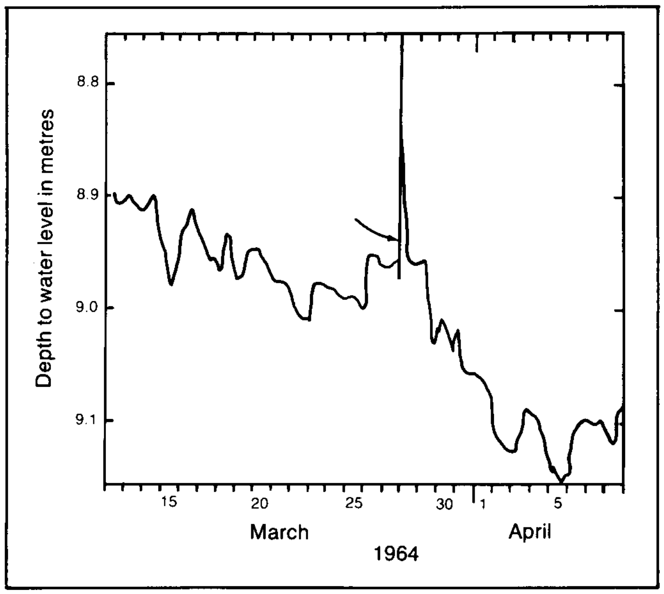


Figure 14. Groundwater-level response caused by a distant earthquake, Elnora, Alberta (after Gabert, 1965).

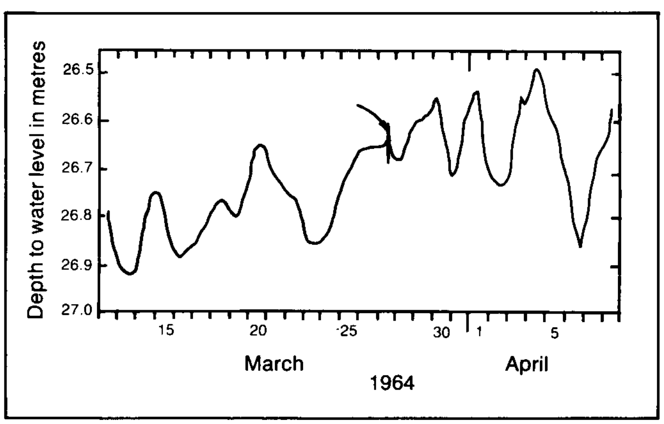


Figure 15. Groundwater-level response caused by a distant earthquake, Airdrie, Alberta (after Gabert, 1965).

dicates that a temporal stress was introduced into the aquifer as a result of the earthquake.

An indication of permanent aquifer deformation is shown by the permanent downward shifting of water level for a well in a confined aquifer at Airdrie (figure 15).

Typical hydrographs for Alberta

A number of annual hydrographs have been selected to show typical water-table or hydraulic-head level changes during the calendar year for both the Alberta plains and foothills/mountain areas. The hydrogeologic environment and groundwater regime factors affecting water-level fluctuations are many and complex; therefore, many nontypical responses can be documented. The hydrographs are considered to be uninfluenced by withdrawal of water from wells, are complete and selected from long periods of record. The hydrographs show continuously measured water levels and patterns that are repeated the most frequently in other years.

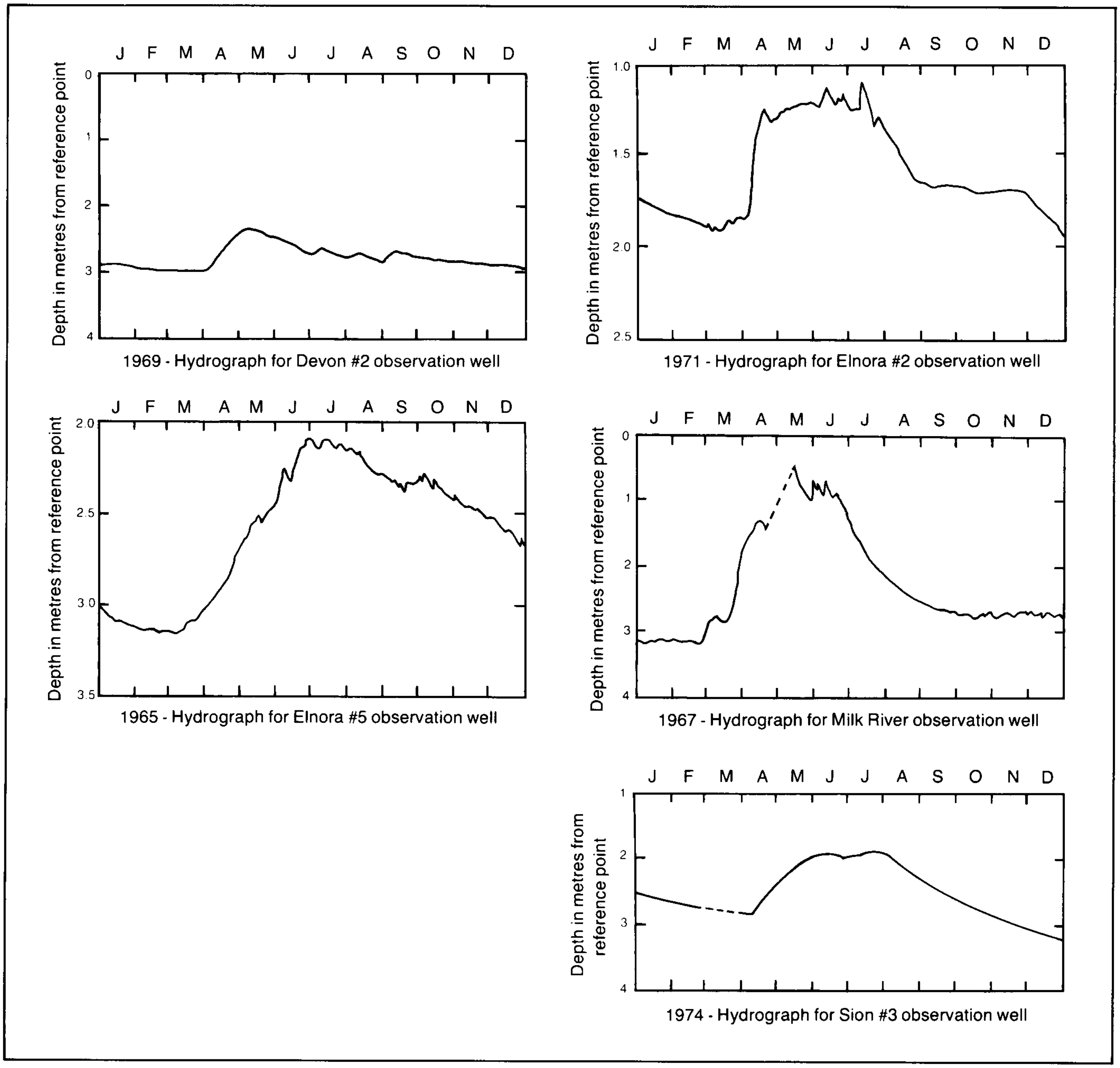


Figure 16. Typical water-table hydrographs for the Alberta plains.

Water-table hydrographs

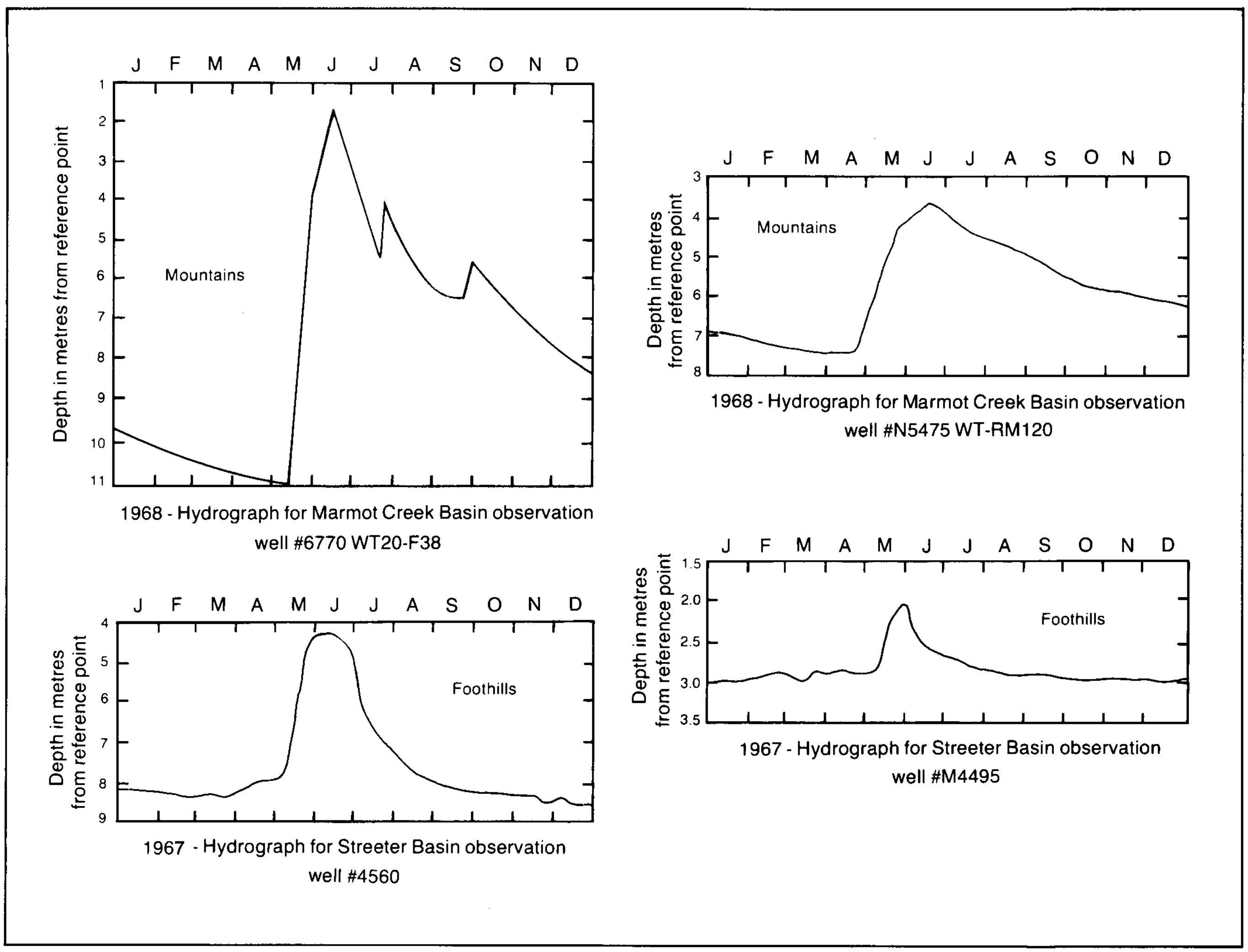
Typical water-table hydrographs for the Alberta plains area (figure 16) show a marked rise in water level in spring, which is related to recharge to the groundwater reservoir from snowmelt. This rise normally begins in late March or early April and continues to June or July when the water level begins to decline. Rises in water level in the summer or fall usually are the result of recharge from heavy precipitation. Water levels generally continue to gradually decline during winter months.

For the foothills/mountain areas, water-table hydrographs (figure 17) are similar in character to those of the plains except that water level rises occur in late April or early May because melting of snow and thawing of the ground occur later. Rises are normally more rapid and recession curves steeper than for the plains area.

Hydraulic-head level hydrographs

Hydraulic-head level measured in observation wells completed in confined aquifers is considered an average level for the aquifer interval open to the well. The most common hydrograph is similar in character to those for water-table level; usually, there is a phase lag between hydraulic head and water-table level responses to a given cause. The "loading" or addition of water to the saturated zone at the water table results in a hydaulic-head level change due to a change in hydrostatic pressure at the point of measurement. The magnitude of fluctuation in hydraulic-head level for the same event will usually be less with increasing depth of the aquifer. Hydrographs selected for the Alberta plains area (figure 18) are typical examples. Three of these hydrographs are from the same locality for the same year. Elnora #4 and #6 are shallow wells and Elnora #7 is a deep well, relatively. The phase lag is evident for Elnora #7 compared to Elnora #4, but the greatest phase lag is for Elnora #6. Very deep aquifers (figure 18, Gull Lake) remain essentially constant.

Hydraulic-head level hydrographs for the foothills region (figure 19) typically show several water level rises in the spring and early summer and declining water levels from mid or late summer until springtime.



1968 - Hydrograph for Marmot Creek Basin observation well #6770 WT20-F38

1968 - Hydrograph for Marmot Creek Basin observation well #N5475 WT-RM120

1967 - Hydrograph for Streeter Basin observation well #4560

1967 - Hydrograph for Streeter Basin observation well #M4495

Figure 17. Typical water-table hydrographs for the Rocky Mountains and foothills of Alberta.

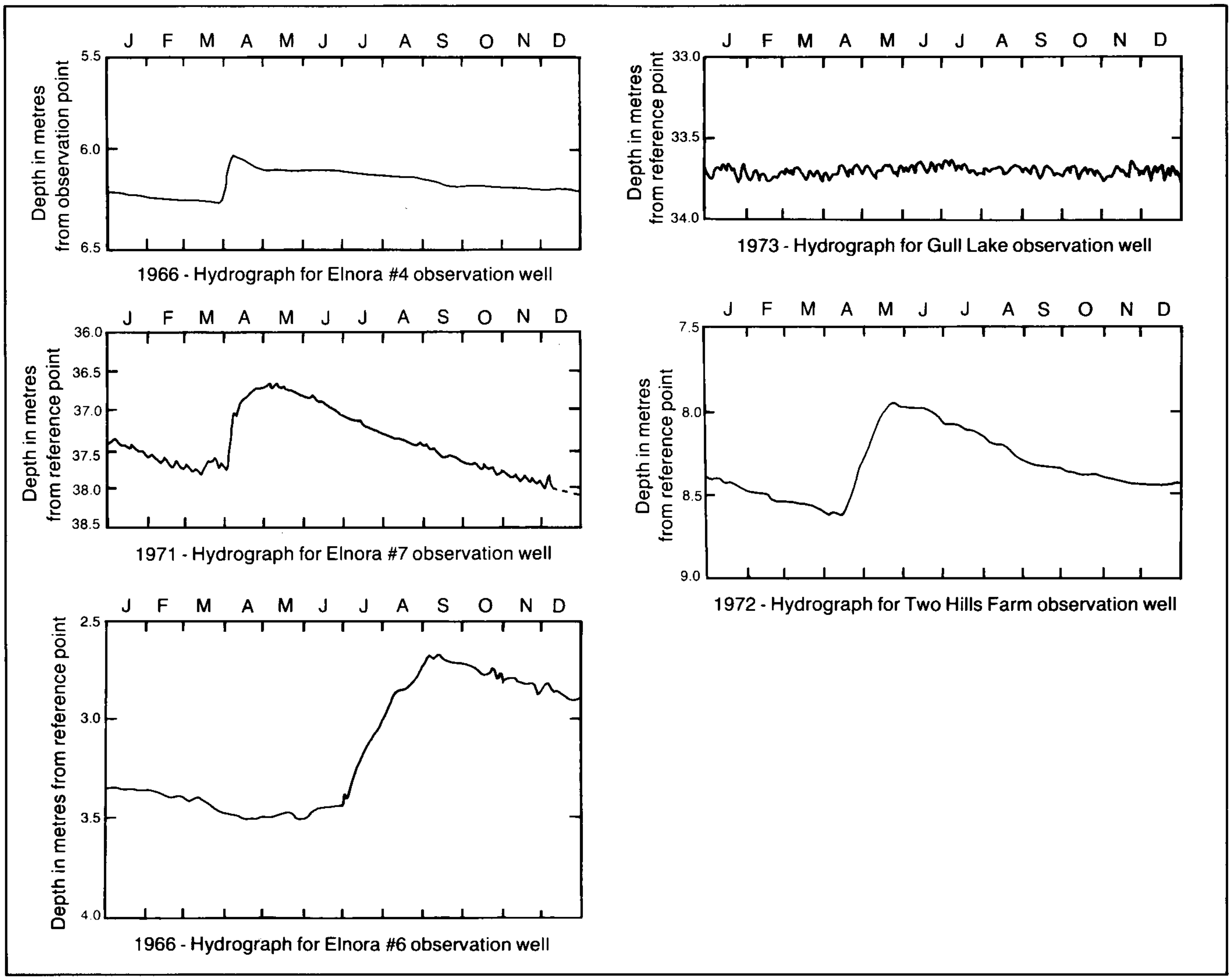


Figure 18. Typical hydraulic-head level hydrographs for the Alberta plains.

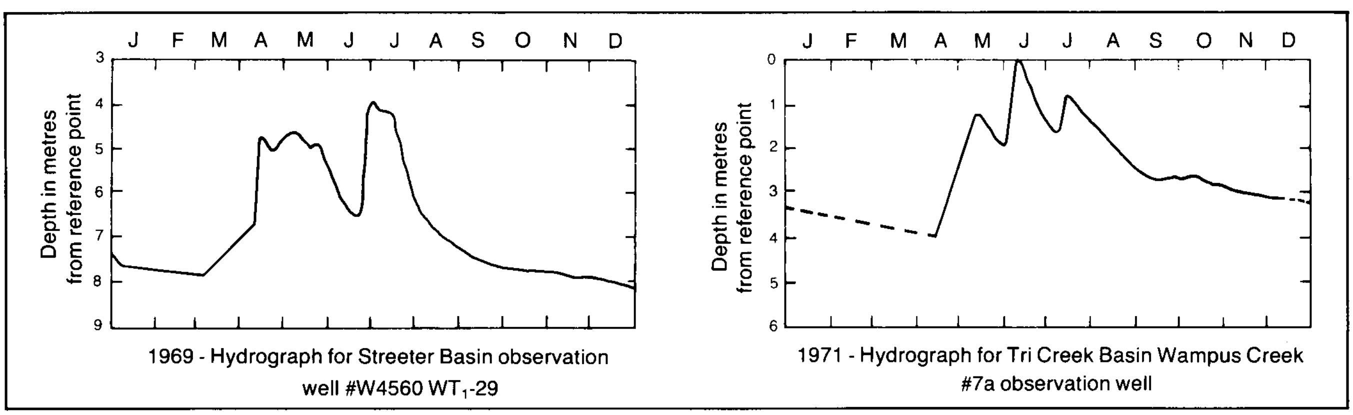


Figure 19. Typical hydraulic-head level hydrographs for the Alberta foothills.

Activities of man that cause groundwater-level fluctuations

Groundwater withdrawal from wells

The estimated use of groundwater annually in Alberta is 137 237 000 m³ (Hess, 1984). Table 2 shows the distribution of groundwater use for municipal, rural, industry and agricultural (mainly livestock watering) uses. Every producing water well causes a lowering of

Table 2. Estimated groundwater use in Alberta

Water user	Volume of water used annually (1000 m³)		Groundwater % of total
	Total	Groundwater	
Municipal[1]	402,460	8,049	2
Rural[2]	34,803	30,235	87
Industry[3]	686,279	17,898	3
Agriculture			4
Livestock	90,061	81,055	
Irrigation	1,867,413	0	
Total	3,081,016	137,237	4

[1] Communities with populations >1000
[2] Communities with populations <1000 and farm population
[3] Self-supplied only, including thermal water used by industry
Reference: Hess, Paul J. (1984):

water levels in the vicinity of the well, but measurements of these changes usually are available only for wells from which municipal and industrial water supplies are obtained. It is important to keep in mind that groundwater is a renewable resource and that, although the withdrawal of water from wells causes a decline in water levels for some particular distance surrounding the well or wells, water levels recover to former levels over a period of time (days to years) when pumping is stopped. This is partly because water is continuously percolating downward through the unsaturated zone to the water table, replenishing the supply of water in storage.

Hydrographs (appendix C) discussed in this section of the report are records of water level fluctuations in observation wells completed within the radial influence of a pumping well(s) in the same aquifer. Therefore, observed trends in water level are primarily due to changes in pumping levels, although wider-ranging, seasonal effects are also observable on the majority of hydrographs.

An excellent example of the effect of groundwater production in a municipal well field on water levels of a confined bedrock aquifer has been studied in detail near Olds, Alberta (Tóth, 1966 and 1973). A water-well field was established there as a result of a detailed hydrogeological study (Tóth, 1966) conducted in 1964-1965. Production from three pumping wells began in late 1964 or early 1965. From that time, an observation well was established in the vicinity (figure 20) to monitor groundwater levels.

A second study of the hydrogeology and yield evaluation of the well field was carried out in 1970-1971 (Tóth, 1973). A network of 17 observation wells (figure 20) was measured manually on a weekly basis by staff of the town of Olds. Results of the town's program to accurately monitor production and water levels for the period 1972-1973 were published in 1974 (Hydrogeological Consultants Ltd., 1974). Olds' monitoring program is probably the best one in Alberta and is an example for other centers to follow.

The water-producing formation consists of consolidated continental sediments that are overlain by clays, sands and gravels. No extensive aquifer can be distinguished. The zone of consistently high permeability is associated with a buried channel in the bedrock and is interrupted by a hydraulic barrier (figure 20). Figure 21 shows the decline in water levels from 1964-1965, when pumping began, to 1970-1971. Toth (1973) also presents information that suggests that the pumping of water for the town wells is the main factor causing the declining water levels. Information supplied by Hydrogeological Consultants Ltd. (1974) shows the decline in water levels from the lowest measured levels in 1971 to the lowest measured levels in 1973 (figure 22). This decline is acceptable in

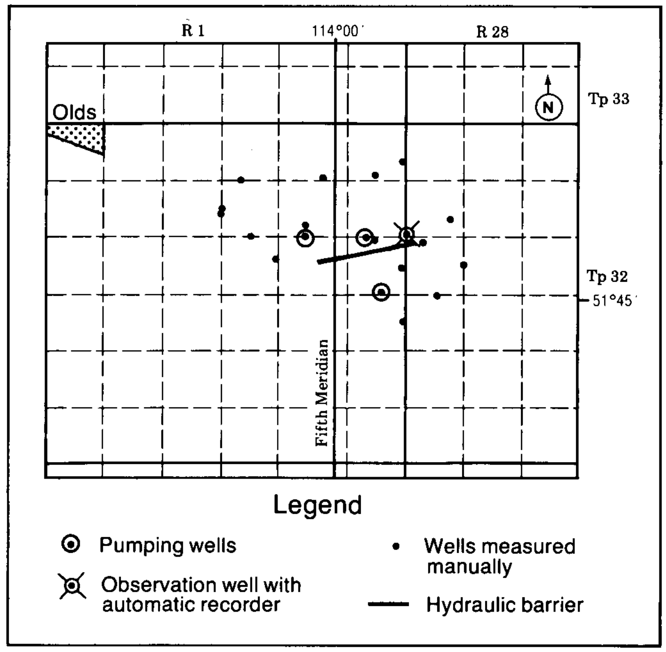


Figure 20. Location of well field, pumping wells and observation well.

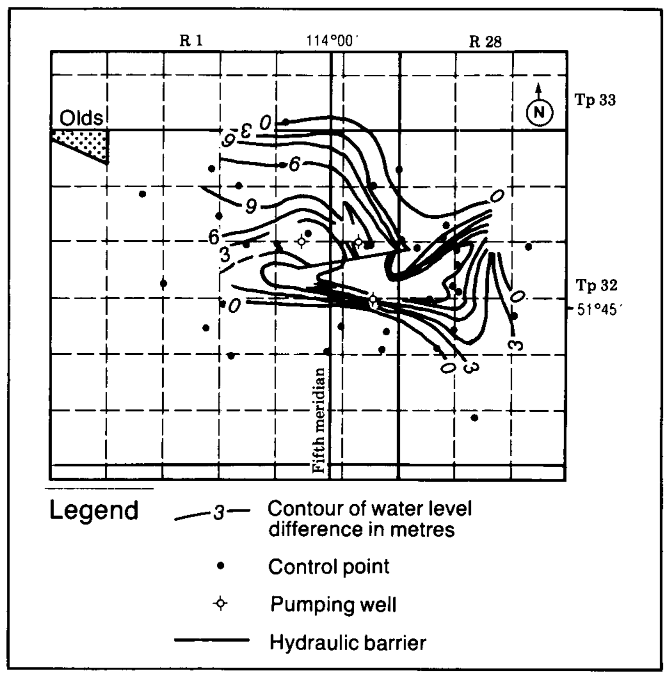


Figure 21. Decline in water levels from 1964-1965 to 1970-1971.

respect of total production from the three wells of 270 000 and 255 000 m³ in 1972 and 1973, respectively. Figure 23 is a hydrograph of water levels in the observation well throughout the production period and following cessation of pumping in the summer of 1977 when a surface water supply was established for the town. It can be observed that the water level gradually declined more than 6 m from the time pumping began in 1964 to mid-1977 when pumping ceased. By the end of 1981, water levels had recovered to close to those measured at the time the well field was established.

Buried valley aquifers

Municipal water supplies for the towns of Edson, Galahad and Killam are obtained from buried valley aquifers. Aquifers at Edson and Galahad are confined, whereas the one at Killam is unconfined. The type of water-level response is therefore similar for Edson and Galahad, but very obviously different for Killam (appendix C). In the confined aquifers, seasonal water-level fluctuations are modified by the influence of production, but water levels rise during the spring time for most years of record. Anomalous fluctuations of water levels are a reflection of production history; examples occurred during 1961, 1965 and 1966 at Edson, and 1973-1974 at Galahad. Water levels in confined aquifers in buried valleys will decline at decreasing rates, assuming constant production. The water level at Edson declined from 19.5 to 30.5 m over a 20-year period ending in 1980 (appendix C). An apparent reduction in production near the observation well in 1981 resulted in a very rapid water-level recovery from 29.8 to 24.0 m. Production from the aquifer at Galahad was underway when the water level in the observation well was first recorded. A curtailment of production in 1973 resulted in recovery of the water level to near 7 m below surface, but renewed production resulted in the water level declining to 8.5 m below surface.

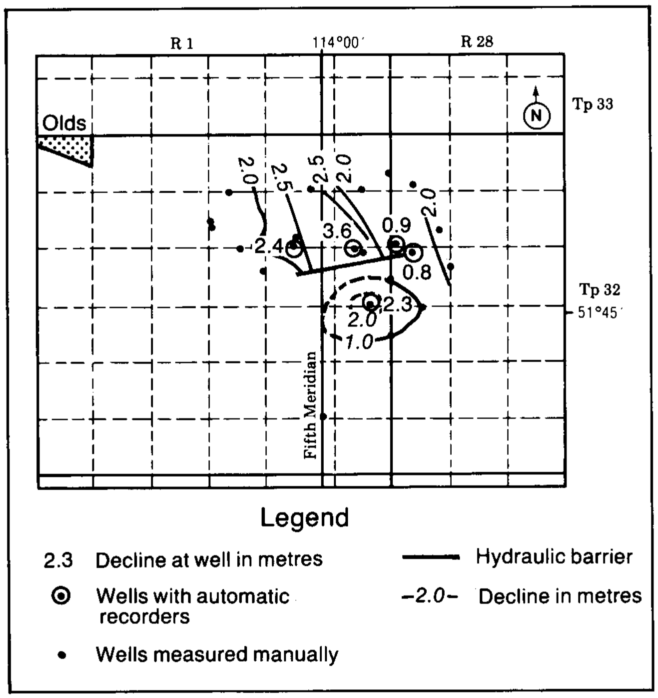


Figure 22. Decline of water level in observation wells from lowest measured level in 1971 to lowest measured level in 1973.

At Killam, water level in the unconfined aquifer predictably shows a range in fluctuation depending on production rates, but the levels remain consistent over many years of production at a constant rate (appendix C). Restriction in the recorded amplitude of water-level fluctuations beginning about 1973 and continuing to the spring of 1980, is a result of poor well response, which uniquely records the clogging of screen slots by the deposition and encrustation of iron compounds. This phenomenon is well known for screened wells completed in unconfined sand aquifers at Killam. The renewed responsiveness of water-level fluctuations in the observation well to pumping from nearby wells in the late spring of 1980 shows the successful removal of the encrustation by acidification.

At the location of the Stettler 1962-4 observation well, a production well was completed in a confined, buried valley aquifer (VandenBerg, 1962) for a town supply in 1963, but production from the well didn't begin until early 1969. Completion of a second production well near the observation well early in 1977 resulted in a noticeable decline of water levels in the aquifer at that location (appendix C). The water level, however, appears to have stabilized somewhat at the lower level by 1981. The increased difference between maximum and minimum water levels measured after 1976 show the combined effect of two nearby production wells on the water level in the aquifer at the location of the observation well.

Observation wells Redwater #1 and #2 (appendix C) are completed in an unconfined, buried valley aquifer known to be hydraulically connected with the North Saskatchewan River (Stein, 1976). Redwater #1 is located to the west of the river valley near a farm well

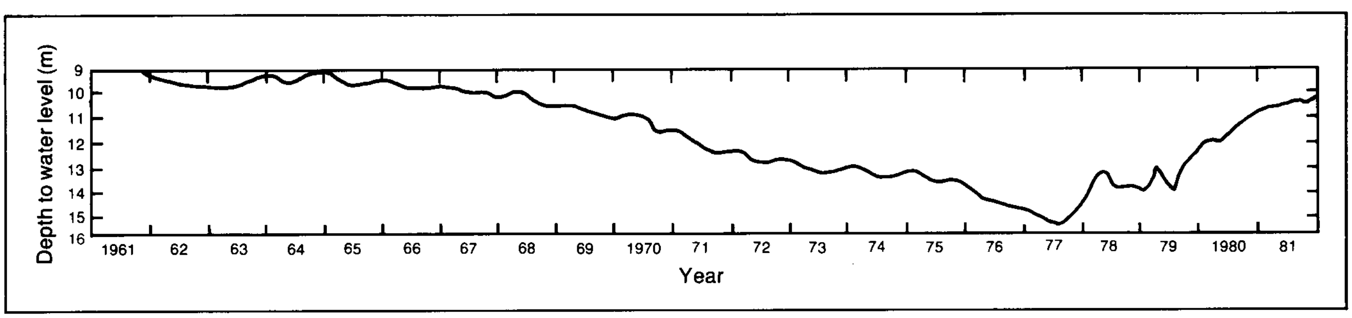


Figure 23. Hydrograph of observation well in Olds water-well field.

completed in the aquifer, and Redwater #2 is located in the valley near the river. The water levels for the two wells correlate with time and are composite levels showing mainly the amplitude of fluctuations caused by pumping of the farm well (particularly Redwater #1) and changes in water level due to fluctuations in river stage.

Another example of water-level fluctuations in an unconfined, buried valley aquifer is documented for the Medicine Hat observation well (appendix C). A large industrial water supply has been developed in this aquifer, which is also hydraulically connected to the South Saskatchewan River (Farvolden et al., 1963). Water from the river is induced by pumping to move through the gravel terraces to the production wells. The hydrograph of the observation well at Medicine Hat (appendix C) is a composite water level, primarily showing fluctuations due to pumping from wells and the effect of river-level fluctuations. Both these influences are dominant over other groundwater-level responses. The hydrograph indicates that the critical period with respect to low groundwater levels is basically from August to mid-November. The hydrograph shows a marked increase in water production from the aquifer at the beginning of 1977.

Sandstone aquifers

Water-level responses due to natural phenomena and production of groundwater in confined sandstone aquifers are illustrated by hydrographs of observation wells at Beaverlodge, Delia, Entwistle, Foremost, Innisfail, Leduc, Ponoka, Sherwood Park, Stettler, Wainwright and Wetaskiwin (appendix C). The trend of these hydrographs is predominantly influenced by changes caused by the production of groundwater from wells.

Beaverlodge obtains groundwater from both sandstone and unconsolidated sand and gravel. The decline in water level recorded in the observation well recovered considerably in 1964, when one of two water wells was taken out of production to be serviced. In addition to this, a new well was established at a distant location from the observation well. The water level was essentially stable from 1971 to 1976, when a surface-water source was established and water wells were abandoned. Since that time, the groundwater level measured in the observation well has recovered to the level recorded in 1959 (appendix C).

Production at Delia, as evidenced by water-level response (appendix C) has been much more erratic, with some heavy demand periods, such as during the last half of 1966, and stoppages in production in 1974. The rapid decline or recovery of the water level is obvious during these times.

Water levels in the observation well at Entwistle declined until mid-1971, recovered to the end of 1979 and then again began to decline (appendix C). The recovery since 1971 was due to a nearby production well being abandoned and a new well (or wells) being constructed at a considerable distance from the observation well. Increased production of water from the aquifer in late 1979 resulted in a downward trend in water level.

The water supply for Foremost is obtained from a classic artesian aquifer, the Milk River Sandstone, which was studied in detail by Meyboom (1960). The observation well is 229 m deep. The water level has declined continuously over the period from 1957 to 1974, from 29 to 70 m, with some recovery evident in 1975 (appendix C). Recent measurements of water level in late 1984, however, show that the water level in the observation well has continued to decline to about 80 m below surface. There is an atypical pattern of troughs in the hydrograph during summer months, and crests during winter months. These are explained by recovery of the water level when discharge from hundreds of abandoned flowing wells completed in the aquifer is retarded or stopped. This is because these wells are frozen near, or at, the ground surface during the winter.

Production at Innisfail appears to have been at a very steady rate from 1965 to 1981, with water levels declining from 4.6 to 19.8 m (i.e. 15.2 m) by 1978 and then stabilizing from that time to December 1981 (appendix C).

The water level trend in the Leduc observation well results from private water well use and variations in town water supply for a few years following 1959. Since 1959, Leduc has obtained its water supply from Edmonton by pipeline. The hydrograph (appendix C) shows fairly consistent rises in water levels in the late spring, due to recharge to the saturated zone from snowmelt. Since 1971, individual use of groundwater in the vicinity of the observation well has increased, but the water level has remained rather constant from 1977 to 1981.

Ponoka obtains water from thick, very productive sandstones. The hydrograph for the observation well generally indicates heaviest withdrawals of water during the summer months (May to September). A gradual increase in production has occurred since 1975. The magnitude of fluctuations in water level due to pumping effects increased markedly in 1981 when a water well was completed close to the observation well. Over the 18 years of record, the water level has declined more than 9 m (appendix C).

Many dwellings on small acreages in the vicinity of Sherwood Park obtain water from low-yielding, fine-grained sandstones. The cumulative effect of several wells producing water for mainly domestic purposes is recorded for one area on the Sherwood Park hydrograph (appendix C). Decline in the water level of about 1.7 m occurred over the period from 1960 to 1964, after which levels remained fairly constant until 1971. In early 1972, the water level began to recover from about 6.4 m below surface and reached a level of 5.5 m below surface at the time the well was abandoned in 1977.

Stettler observation wells #6 and 1960-4 are completed in confined sandstone aquifers (Meneley, 1959). Water wells near #6 were not used as major water-source wells after 1961, but the recovery of water levels measured in the observation well was less rapid in the late 1960s and again in the mid-1970s. These trends most likely are due to increased production from the aquifer. Well 1960-4 established near producing wells shows an increased rate of drawdown from 1975 to 1979 compared to the previous seventeen years of water level measurement, but water level in this well has been very constant from 1979 to the end of 1981. The sharp drop in water level in June 1980 probably is caused by pump testing of a nearby well or excessive production for some reason for a short period of time.

Observation well Wainwright Town is completed in a confined sandstone aquifer near a producing well. The hydrograph shows sharp declines in water level during the heavy summer demand periods (appendix C). Overall production appears to have been consistent from 1963 to 1976. During 1976, production from the aquifer near the observation well has increased and water level has continued to decline to the end of 1981.

Westaskiwin #26 and 1962-2 are completed in confined sandstone aquifers from which the city of Wetaskiwin obtains water. The groundwater is used in conjunction with a surface water supply. Wells near the location of Wetaskiwin #26 have been abandoned since the early 1960s, although the water level at the location of the observation well appears to have been influenced by town wells located long distances away until 1973 when the rate of recovery increased (appendix C). For the period of record, the water level has recovered about 2.7 m. The water level in Wetaskiwin 1962-2 is presently strongly influenced by nearby pumping wells, but the water level rises in late spring following the snowmelt period. This rise is more obvious and consistent for the period from 1971 to 1981 and less obvious for the period from 1963 to 1970. The average net change of water level recorded at the end of the 22 year period of record compared to the initial level is in the order of -1.3 m.

Coal aquifers

Confined coal aquifers in Alberta commonly have fracture permeability; fluctuations of water level caused by hydrogeologic factors or the effect of pumping wells is similar to those observed for confined sand or sandstone aquifers. Barrhead (appendix C) is an example, and the main influence on water level is pumping of nearby water wells. The lowest water levels are evident during the July to September period and the current trend is to lower water levels.

Sand, or sand and gravel aquifers

Grimshaw Kerndale and Grimshaw Mercier observation wells are completed in deep and shallow gravel aquifers, respectively. The water level for both aquifers normally rises as a result of recharge from spring snowmelt (appendix C). Grimshaw Kerndale observation well is completed in a confined aquifer influenced by pumping wells. The rise in water level in 1974 is caused either by extraordinary recharge to the groundwater reservoir from snowmelt or curtailment in pumping of nearby wells. This water level response is also true of Grimshaw Mercier which is completed in an unconfined aquifer from which water discharges as springs. These springs have been developed to provide a water supply for the Town of Grimshaw. The noticeable drop in water level for this well in 1981 was caused by the dewatering of gravel pits near the observation well.

Water-level fluctuations for a confined sand aquifer are shown for observation well Devon #1 (appendix C). A farm water-supply well is located nearby. The farmer states that production was consistent for the period 1960 to about 1970, when production was substantially curtailed. Water level in the observation well then recovered about 2 m.

The observation well at Lethbridge is also completed in a confined sand aquifer. Pumping of this well was stopped in 1963 when a surface water supply was established. Water level in the well has recovered close to 10 m at present, but essentially full recovery was evident by 1976, over a period of fourteen years.

Artificial recharge

Artificial recharge to the saturated zone results in a mounding effect on the water-table surface. For a constant rate of recharge at a given point, the rise in water-table level will be maximum with decreasing effect radially. Confined aquifers will reflect recharge to the saturated zone by an increase in hydraulic-head levels. The city of Camrose, Alberta, successfully and economically obtained its water supply for more than 20 years from an unconfined gravel aquifer which was artificially recharged with water from Driedmeat Lake, located adjacent to the aquifer (Gabert, 1978). The water supply delivery system (figure 24) includes a settling pond adjacent to the lake, an intake pumping station with a microstrainer, a pipeline to deliver water to the recharge pits, a pumphouse with two wells to ex-

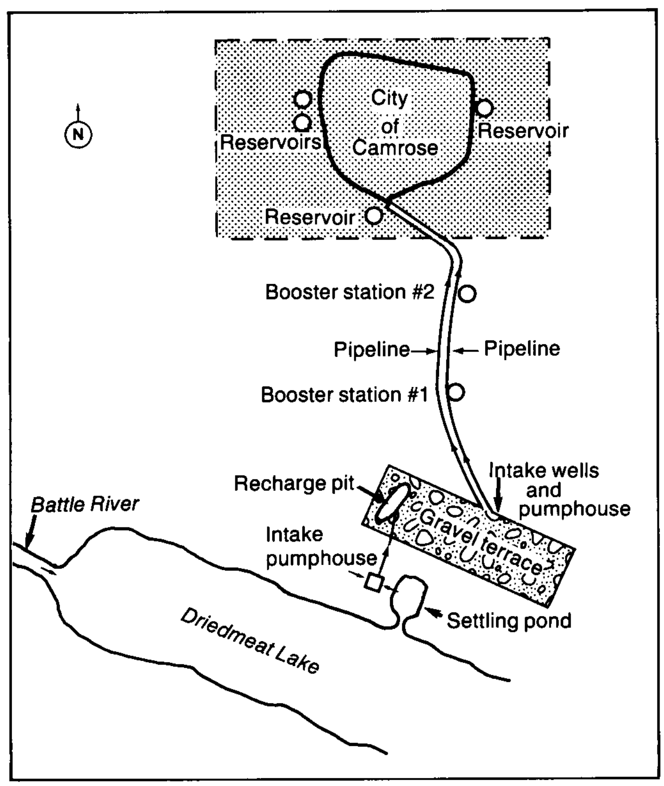


Figure 24. Sketch of Camrose Water Supply System.

tract water from the aquifer, and two pipelines to the city. The effect of artificial recharge is shown in a two-dimensional cross-section through the aquifer (figure 25) and in a potentiometric map showing the general pattern of groundwater flow (figure 26). The effect of recharge diminishes rapidly away from the recharge pits mainly because of the high transmissivity of the aquifer material and the effect of drawdown caused by the production wells. Delivery rates of recharge water range from 63 to 121 L/s depending on the use and effective filtration of the microstrainer. The system can produce 144 L/s on a sustained basis.

Irrigation

Irrigation can cause substantial rises in water-table levels. The highest water-table levels correspond with major water use in the June to August period. Twinned peaks on the hydrograph are often present (appendix C, Taber-Dunmore). This hydrograph shows that more extensive irrigation was undertaken after 1967. Taber (Lake) hydrograph (appendix C) is a second example of water-table response to irrigation.

Land clearing

Ryckborst (1981) studied the effects of land clearing operations on a small catchment basin (0.06 km²) in west-central Alberta. The hydrology of the basin was investigated four years before and four years after deforestation. Precipitation in the basin averages 500 mm/yr; average runoff is about 80 mm/yr and evapotranspiration is 420 mm/yr. Results showed that during the spring snowmelt period, the groundwater table dropped 0.2 to 0.5 m in recharge areas (figure 27), with a gradual recovery two years later. Deforestation in recharge areas also created a temporarily and only slightly disrupted soil profile with an increased effective porosity. These conditions accounted for an average measured increase in the groundwater contribution to streamflow during the annual snowmelt period of from 1.0 to 1.9 mm/day. In discharge areas (figure 27), groundwater tables rose. The rise of the water tables is associated with decreased effective porosity in those wet and low-lying areas that are compacted during mechanical deforestation operations.

Secondary recovery of oil

Secondary recovery of oil can be achieved by injection of water into oil reservoirs to maintain pressures necessary for oil production. The Coronation observation well is completed in a confined sandstone aquifer that is used by oil companies for secondary recovery purposes. Water is obtained at depths ranging from 55 to 85 m below surface. Production began in 1959 and requirements in 1969 were at least in the order of 4 L/s on a continuous basis. LeBreton (1969) investigated possible detrimental effects of oil company with-

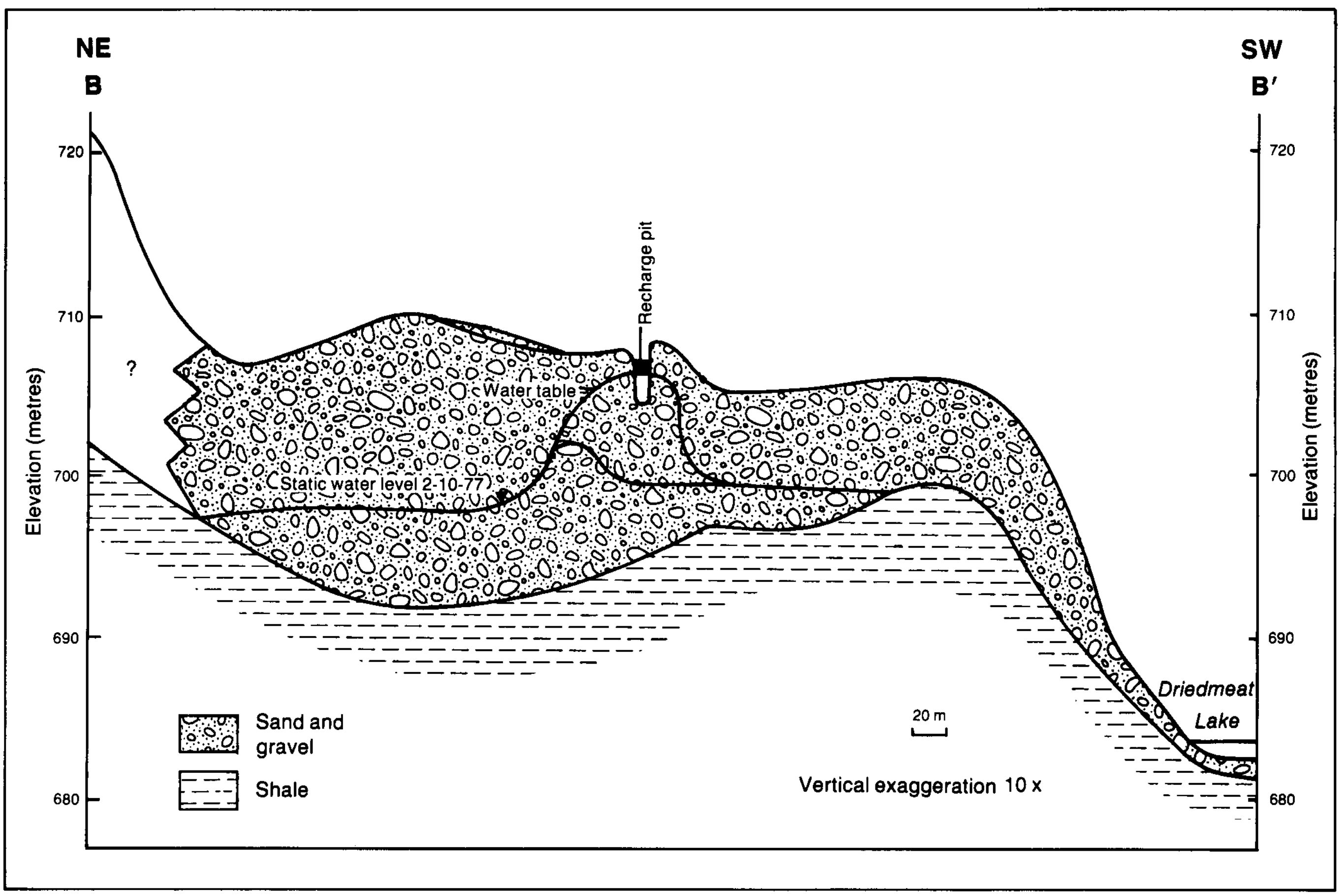


Figure 25. Cross section showing water-table position in aquifer.

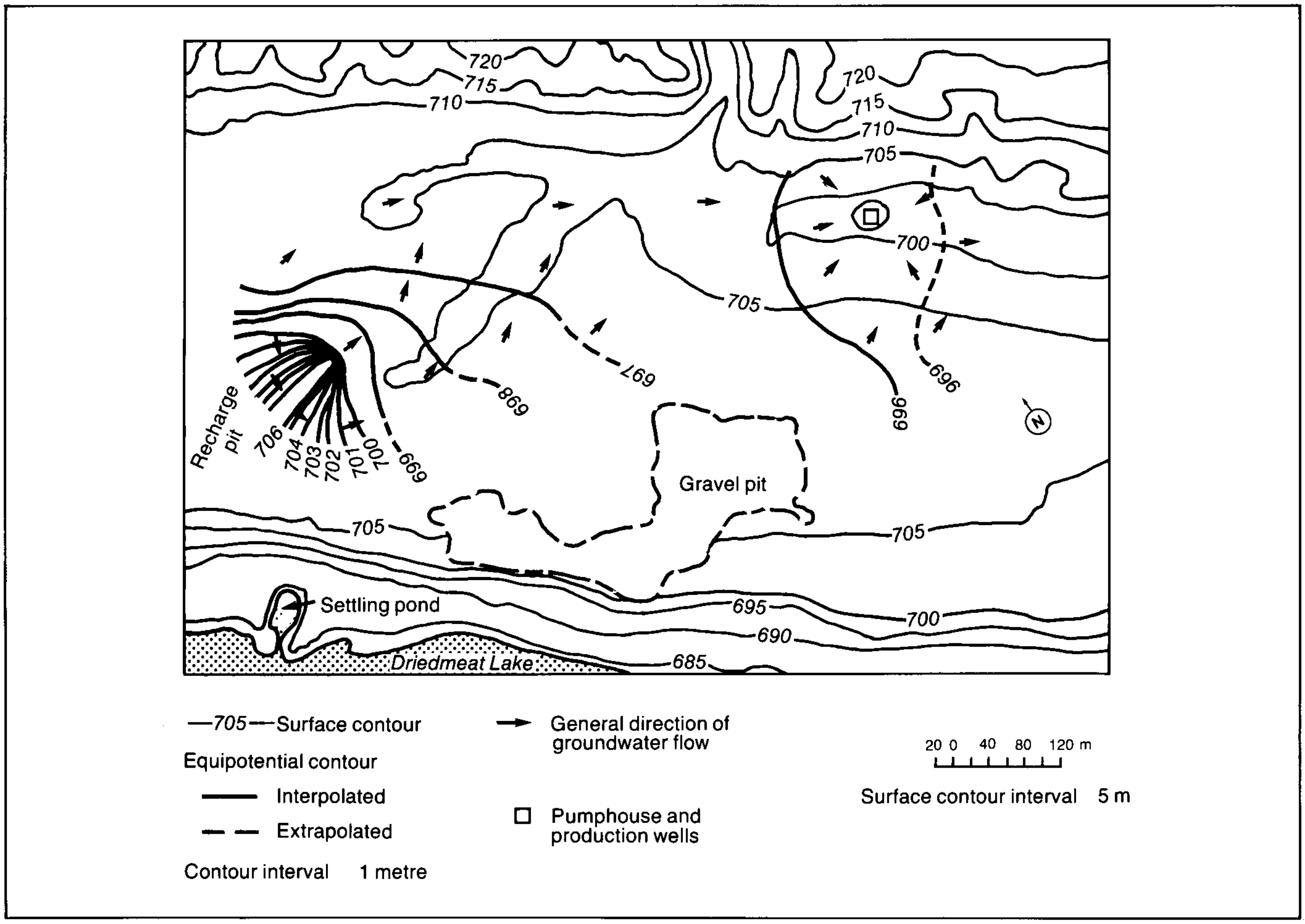


Figure 26. Potentiometric map and general pattern of groundwater flow.

drawals on groundwater. He concluded that recharge to the aquifer does occur, and at a rate sufficient to keep pace with both oil company and farm users. The hydrograph (appendix C) shows a balance between production and recharge evident from 1972 through to the end of 1981, confirming LeBreton's (1969) conclusion. Water level in the observation well has declined about 5 m, but recovery to levels measured in the late fifties is expected when oil production ceases.

The Drayton Valley observation well is located in one of the most productive oil fields discovered in Alberta. Oil was discovered in 1953 and by 1956 it was apparent that secondary recovery would have to be implemented to maintain reservoir pressures (Farvolden, 1961). This was accomplished by injecting fresh water, much of which was obtained from groundwater. The observation well is completed in sandstones that yield water to oil company water-supply wells. The hydrograph shows a gradual decline of about 2.5 m over the years from 1961 to 1974. Production from the aquifer appears to have been considerably reduced in the summer of 1974 and, by the end of 1981, had recovered to the level recorded in 1961, that is, fully recovered. Sharp rises or falls in water level, as recorded in 1961, 1965 and 1975, are the result of producing water wells near the observation well.

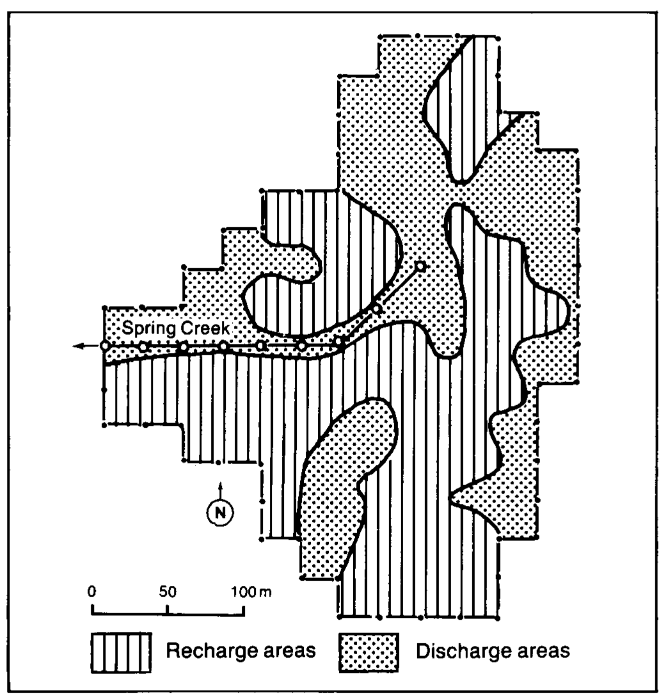


Figure 27. Distribution of recharge/discharge areas in Spring Creek basin during spring snowmelt conditions.

Construction of reservoirs

When reservoirs are constructed and filled with water, groundwater levels in the vicinity of the reservoir will be affected. Water-table levels will rise in the vicinity of the reservoir and the hydraulic-head levels of aquifers exposed below the water level or occurring close to the reservoir will also rise. The magnitude and extent of water-level changes will depend on hydrogeologic conditions and the water level in the reservoir. The effect of Waterton Reservoir on hydraulic-head level in a confined aquifer has been well documented (VandenBerg and Geiger, 1973; Prairie Farm Rehabilitation Administration, 1968 and 1975). In this case, the construction of the dam intersected a buried gravel aquifer (figure 28) and the result, when the reservoir was filled, was a direct hydraulic connection with the aquifer. Test drilling resulted in mapping of the distribution of the main aquifer (figure 29). The reservoir was initially filled during the period from March 18 to June 18, 1965 and water level in the reservoir rose from 1150 to near 1190 m above sea level, that is, a total of about 40 m. The response of water level in the aquifer to water level in the reservoir is shown in figure 30 for observation wells Waterton Dam #1 and #5 for the period 1965 to 1970, inclusive. Hydrographs for the two observation wells to December 1981 are shown in appendix C. The

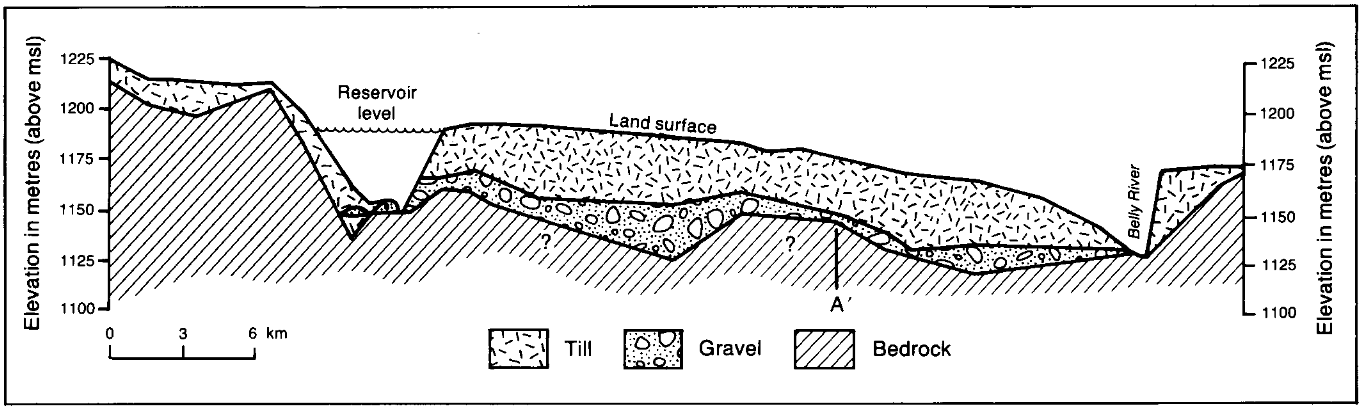


Figure 28. Cross section showing interception of aquifer by dam (after VandenBerg and Geiger, 1973).

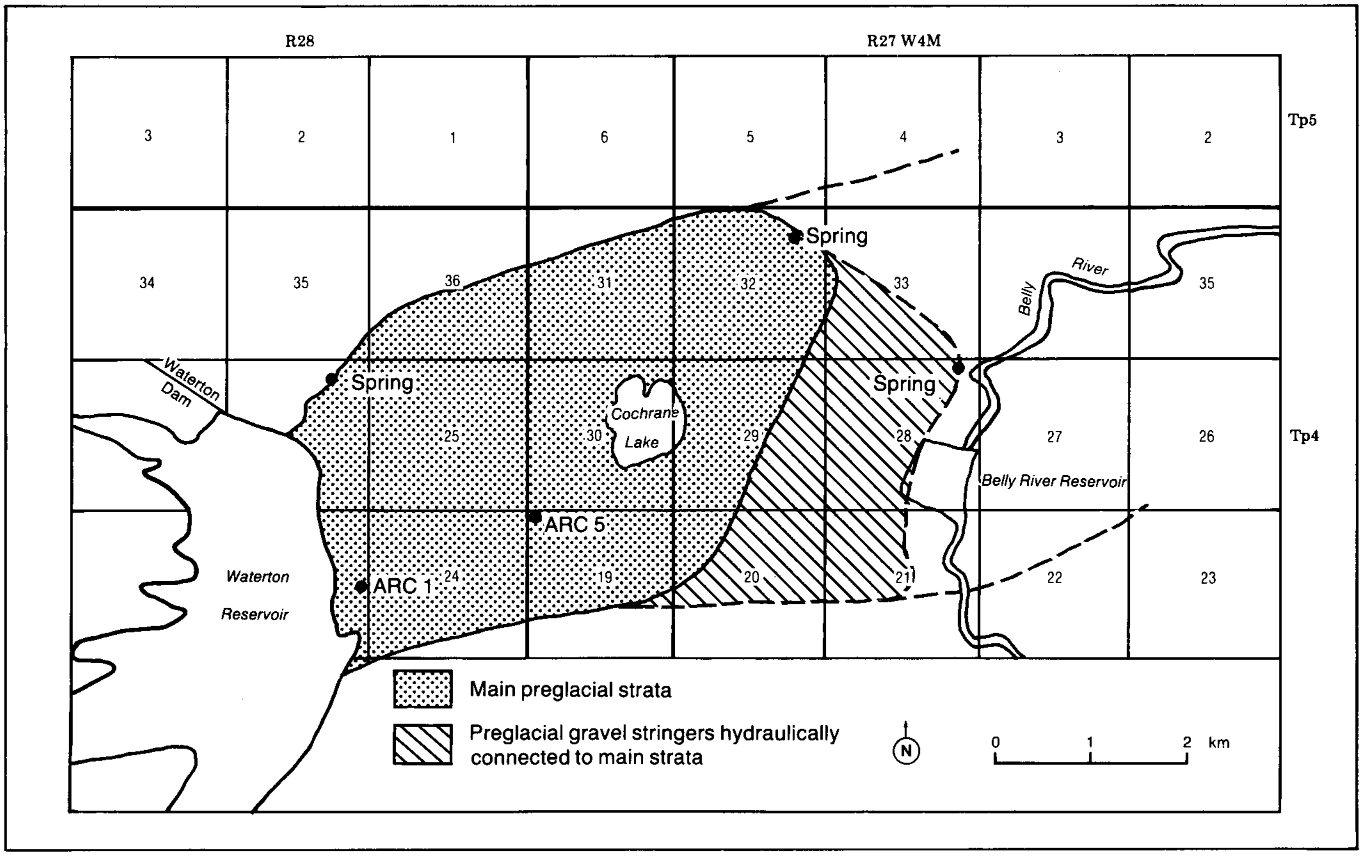


Figure 29. Location of buried valley aquifer and observation wells (After P.R.F.A., 1975).

water levels in the main aquifer strata (figure 29) are quite responsive to the water level in the reservoir, but water levels further east in the area where the aquifer consists of gravel stringers (figure 29) respond rather slowly to changes in water level in the reservoir. Water levels fluctuate 0 to 3 m below the surface in the area immediately downstream of the dam and 0 to 15 m above surface, adjacent to and east of Cochrane Lake (figure 29). Several relief wells were completed in the Cochrane Lake area to prevent farm wells in the area from flowing.

Mining

Strip mining is currently the most common type of mining practiced in Alberta, particularly in exploitation of oil sands and coal deposits. These mines are usually very large scale operations and the long-term effect of mining on water levels has been a matter of strong interest. Because substantial records of water-level responses from pre-mining to post-mining are not available, model assessment of these changes based on research by Schwartz and Crowe (1984) will be presented in this publication. Schwartz and Crowe (1984) presented a model assessment of the post-mining response of groundwater levels in and near coal strip mines. Simulations for regional scale, mine scale and individual spoil hills were completed. Only simulations of the regional effects of strip mining on water levels are reproduced here. In regional scale simulations, the entire mine is a relatively small component of an extensive hydrogeologic system.

In the first simulation of a series (figure 31a) the main effect of mining is to destroy the continuity of the

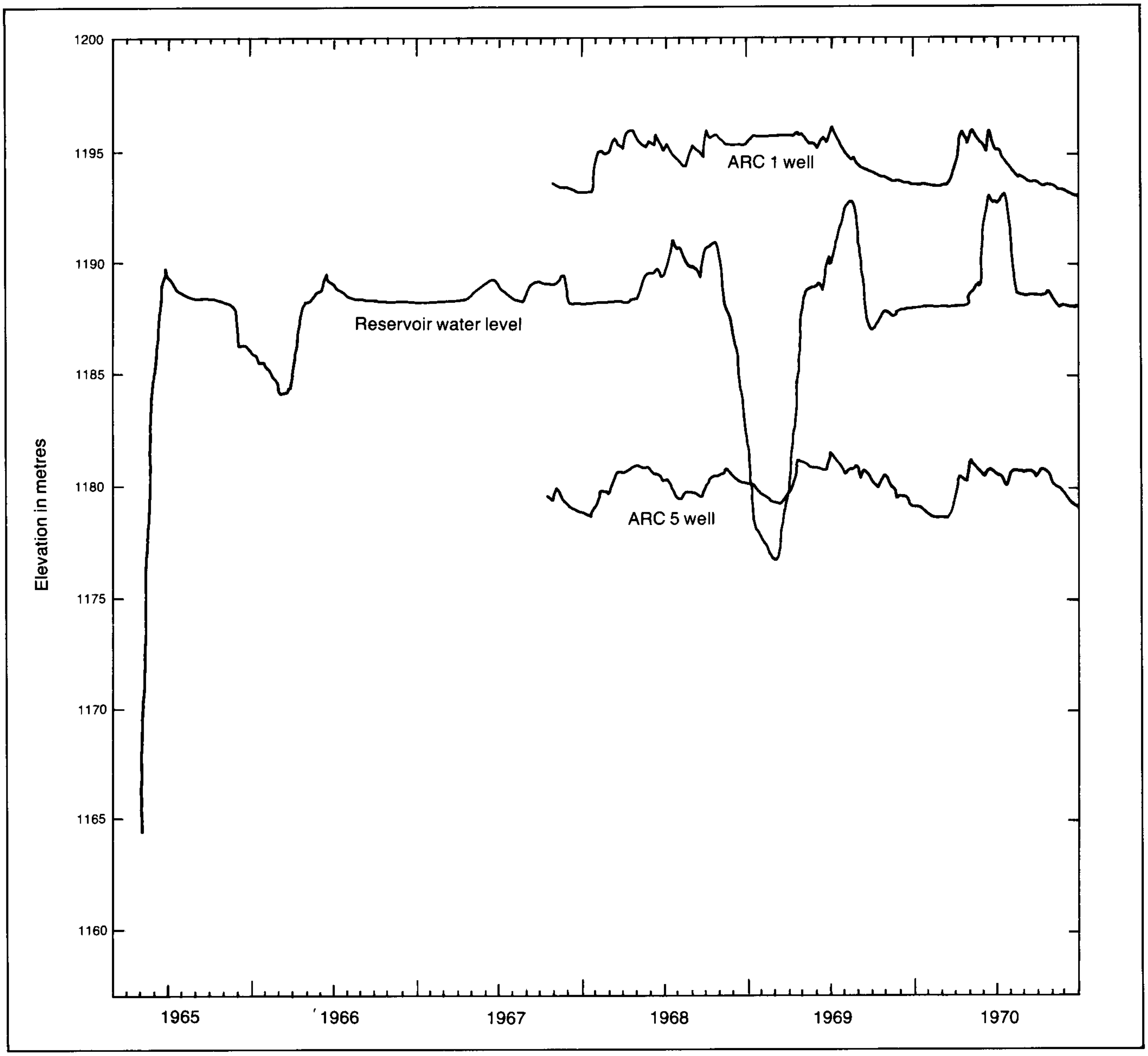


Figure 30. Response of water level in aquifer compared to water-level changes in the reservoir. (After P.F.R.A., 1975).

highly conductive coal. At 8.5 years after mining stopped, the model predicts a significant and widespread lowering of the water-table level. After 32.9 years, the water-table level is recovering and approaching the pre-mining, steady-state, but the final steady-state position of the water table rises to the ground surface upstream of the mine.

The second example (figure 31b) is similar with an end cut left open following the completion of mining. It is assumed that the groundwater discharging into the cut is removed by surface drainage. The response of the water-table level during mining is identical to that in figure 31a because the mining procedure is the same. In the early post-mining period, however, the water-table level is predicted to decline because the end cut constitutes a groundwater discharge area. Keeping the end cut of the mine open results in a permanent decline of the water table on a regional basis; that is, the steady-state water-table position is lower than the premining position.

Simulations of a partially filled and contoured end-cut, but where surface drainage continues to remove all groundwater discharging into the depression, predict a rise in the water-table level following mining. The water-table level rise, however, will be controlled by the elevation of the bottom of the depression (figure 31c).

Figure 32 is the piezometric level measured for a continuous coal interval underlying mine spoil in the Whitewood Mine located west of Edmonton, Alberta. Mining operations began in 1962 and the main reclamation of the site occurred during the period 1969 to 1977 (Alberta Environment, 1980). Mining has strongly affected water levels to at least 1 km west of the mine at this point in time. Water levels were not available east of the mine.

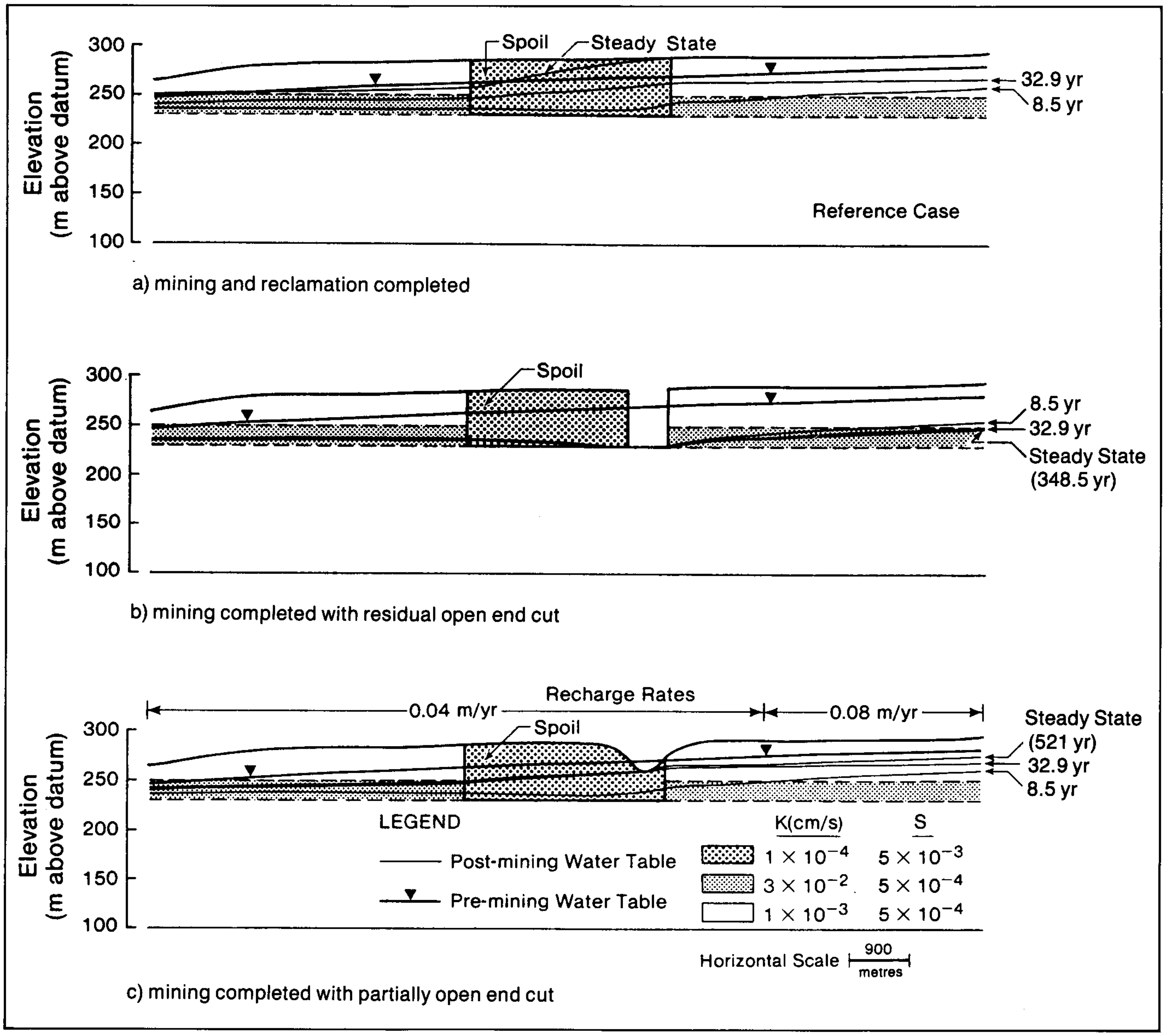


Figure 31. Series of cross sections showing the response in water levels in a strip-mine area with time.

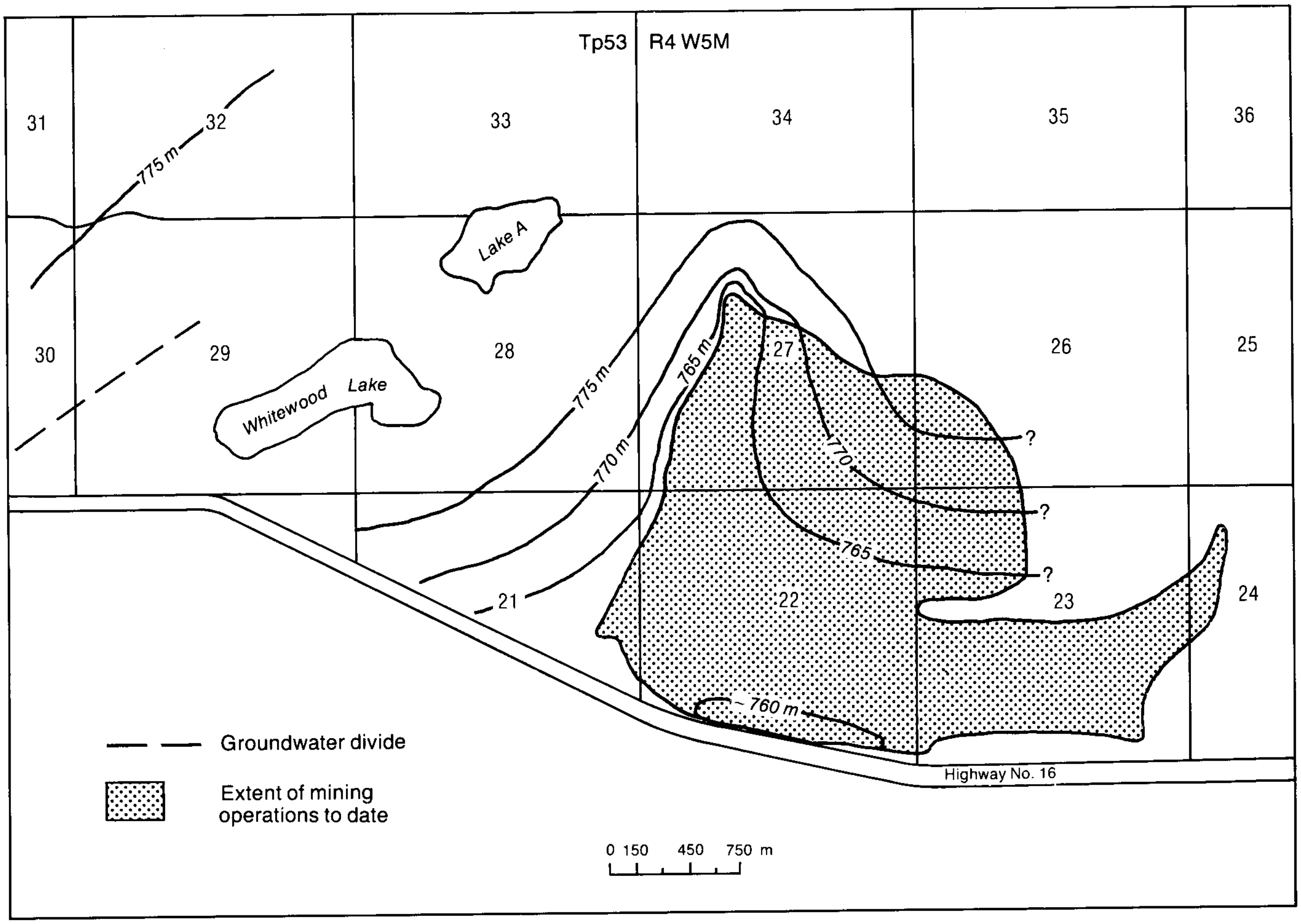


Figure 32. Piezometric level for coal seam underlying spoil, Whitewood Mine, June 1978. (After Alberta Environment, 1980).

General conclusions

Examination of groundwater levels measured in Alberta since 1957 show that, on a provincial basis, natural water levels have remained rather constant within a characteristic range of fluctuations. Exceptions of lowering water levels are present on a local scale as a result of man's activities and most frequently as a consequence of large-scale withdrawal of groundwater from wells. Where pumping has been curtailed or stopped, levels have nearly or fully recovered to those measured prior to production. The period of recovery ranges from a few months to several years, depending on hydrogeologic factors and the net effect of man's activities. Contention concerning groundwater levels in Alberta in the future will result from major activities of man, particularly groundwater exploitation, mining of energy resources (coal and oil sands) and increased irrigation and land drainage.

Emphasis should continue to be given to measuring natural groundwater levels in different hydrogeologic regions of Alberta and in particular where heavy future demand on groundwater resources is expected. On a local scale the change in water levels caused by major activities of man should be monitored before, during and following a particular activity. Reference measurements which are recorded continuously with time are more valuable for interpretive reasons than are occasional measurements.

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Appendix A Information for Groundwater Observation Wells

Well Name	Location Lsd.	Sec.	Tp.	R.	Mer.	Type of[1] Water Level	Period of[2] Record	Depth ft (m)	Well Construction casing	completion	Permeable Interval (ft)	Material	Ground Elevation ft (m)
Ardrossan (U of A testhole)	13	21	53	22	W4	Bn	March 1968 - May 1978	200 (61)	0-80 ft 7 in 80-142 ft 5½ in	80-100 ft slotted slotted	117-120 120-240 145-160	sd & ss coal & ss coal & ss & sh	2278 (694.3)
Barrhead	04	28	58	03	W5	Ba	October 1977-R	286 (87)	0-260 ft 5½ in	260-286 ft Open hole	270-280 281-284	coal & sh stringers coal	2159.34 (658.59)
Beaverlodge	15	36	71	10	W6	Ba	July 1959-R	140 (43)	0-76 ft 4½ in	76-140 ft Open hole	110-114 129-131	sh, ss & cl ss	2425 (739.62)
Buck Creek	16	22	47	07	W5	An	August 1957- May 1977	200 (61)	0-169 ft 5 5/8 in	160-165 ft 165-200 Open hole	194-200	ss	2968.14 (905.78)
Coronation (Hamilton Lake)	09	18	35	09	W4	Ba	October 1958-R	202 (62)	0-160 ft 7 in	160-202 ft Open hole?	160-170	ss	2559.45 (780.12)
Delia	16	05	31	17	W4	Ba	June 1958- June 1976	79 (24)	0-79 ft 6 in		55-65	ss & sh	2974 (907.10)
Devon #	01	36	50	26	W4	Ba	August 1960-R	35 (11)	0-30 ft 4½ in	30-35 ft #15 slot screen	27-35	sd	2202.97 (699.35)
Devon #2	08	12	51	26	W4	An	May 1956-R	25 (8)	0-15 ft 4½ in	15-25 ft slotted	0-25	sd & some cl	2273.77 (693.30)
Drayton Valley	16	18	48	08	W5	Ba	May 1956-R	200 (61)	0-90 ft 8 5/8 in	90-200 ft open hole	121-136	ss	2983.86 (910.00)
Edson	01	22	53	17	W5	Ba	July 1960-R	124 (38)	0-119 ft 4½ in	119-124 ft open hole	119-124	sd & grl	2970 (905.50)
Elnora #2	03	29	35	24	W4	Bn	July 1962-R	17 (5)	0-17 ft 5½ in	12-14 ft slotted	0-17	sd	2913.5 (888.60)
Elnora #3	12	13	35	25	W4	Ba	July 1962-R	62 (19)	0-62 ft 5½ in	30-62 ft slotted	30-62	ss	3169.78 (966.78)
Elnora #4	13	10	35	25	W4	Bn	July 1962-R	45 (14)	0-30 ft 5½ in	18-26 ft slotted 30-45 ft open hole	15-23 23-30	sd sdy cl	3075.89 (938.14)
Elnora #5	16	36	34	26	W4	An	July 1962-R	45 (14)	0-10 ft 5½ in 0-45 ft 4½ in	10-16 ft slotted 30-45 ft slotted	13-45	cl	2933.69 (894.77)

Appendix A (continued)

Well Name	Location Lsd.	Sec.	Tp.	R.	Mer.	Type of[1] Water Level	Period of[2] Record	Depth ft (m)	Well Construction casing	completion	Permeable Interval (ft)	Material	Ground Elevation ft (m)
Elnora #6	01	34	34	26	W4	Bn	July 1962-R	31 (19)	0-31 ft 5½ in	25-31 ft slotted	26-30 30-31	ss coal & sh	3013.06 (918.38)
Elnora #7	13	21	34	26	W4	Ba	July 1962-R	150 (46)	0-130 ft 5½ in	130-150 ft slotted	130-146 146-150	sh & ss coal	3363.10 (1025.74)
Entwistle	03	20	53	07	W5	Ba	May 1961-R	110 (34)	0-? ft 4½ in	?-110 ft open hole	43-75	ss	2566.77 (782.86)
Foremost	16	17	06	11	W4	Ba	Jan. 1957- Apr. 1975	750 (229)	0-400 ft 4 in 400-750 ft 2 in	slotted	522-750	ss	2930 (893)
Galahad	12	23	41	14	W4	Ba	October 1960-R	116 (35)	0-100 ft 4½ in	100-116 ft slotted	80-116	sd & grl	2311.68
Grimshaw- Kerndale	04	13	83	25	W5	Ba	August 1965-R	175 (53)	0-110 ft 5½ in	100-110 ft slotted 100-175 ft open hole	90-123 134-152	sd & grl ss	2160 (658)
Grimshaw- Mercier	05	29	83	23	W5	Aa	September 1965-R	63 (19)	0-49 ft 4½ in	25-35 ft slotted 49-63 ft open hole	32-58	sd & grl	2115 (645)
Gull Lake	01	22	42	01	W5	Bn	December 1964-R	733 (224)	0-300 ft 4½ in	300-733 ft open hole	300-733	ss & some coal	2952.32 (900.1)
Hand Hills #1	04	28	29	16	W4	Ba	October 1965-R	315 (96)	0-303 ft 7 in	303-315 ft open hole gravel fill	303-315	coal & sh	3329.95 (1014.97)
Hand Hills #2	04	28	29	16	W4	Ba	October 1965-R	133 (41)	0-133 ft 7 in	117-128 ft slotted	119-127	ss	3328.72 (1014.90)
Innisfail	04	06	36	28	W4	Ba	July 1965-R	145 (44)	0-90 ft 5½ in	90-145 ft open hole	90-145	ss & some slst	2930.88 (893.91)
Killam	03	17	44	13	W4	Aa	November 1963-R	95 (29)	0-91 ft 4½ in	91-95 ft #10 slot screen	45-95	sd	2215.35 (675.24)
Leduc	08	26	49	25	W4	Ba	October 1956-R	200 (61)	0-23 ft 6 in	23-72 ft open hole	23-72	ss & coal	2414.09 (736.29)
Lethbridge	10	09	08	21	W4	Ba	September 1962-R	190 (58)	0-54 ft 4½ in	54-69 ft #10 screen	54-69	sd	3000 (915)

Well Name	Location Lsd.	Sec.	Tp.	R.	Mer.	Type of[1] Water Level	Period of[2] Record	Depth ft (m)	Well Construction casing	completion	Permeable Interval (ft)	Material	Ground Elevation ft (m)
Lloydminster	10	01	50	01	W4	Ba	September 1957-R	200 (61)	0-? ft 6½ in	?	170-290	ss	2118.71 (646.20)
Mannville	08	25	50	09	W4	Ba	July 1959-R	88 (27)	0-? ft 3½ in	?	?		2047.23 (624.40)
Marmot Creek S 5250 WT	14	11	23	09	W5	An	October 1964-R	40 (9)	0-40 ft 4½ in	slotted open hole		grl & ss	5252 (1652.10)
Marmot Creek S 5430 WT	04	14	23	09	W5	An	October 1964-R	30 (9)	0-26 ft 4½ in	26-30 ft open hole		grl	5420.34 (1652.10)
Marmot Creek N 5475 WT	06	14	23	09	W5	Bn	July 1965-R	120 (37)	0-120 ft 4½ in	slotted		till	5475 (1668.7)
Marmot Creek S 6170 WT	06	15	23	09	W5	An	July 1965-R	49 (14)	0-47 ft 4½ in	43-47 ft slotted	43-47	till	6130 (1869)
Marmot Creek N 6770 WT	11	22	23	09	W5	An	July 1965-R	38 (12)	0-38 ft 4½ in	slotted		till & sh	6725 (2049.7)
Medicine Hat	15	32	12	05	W4	Ba	September 1959-R	70 (21)	0-? ft 6½ in	?	20-58	grl	2162.92 (659.69)
Milk River	14	24	02	15	W4	An	December 1956-R	31 (9)	24 ft concrete	? culvert	?	sand ?	3250 (991.25)
Olds #147	04	30	32	28	W4	Ba	November 1961-R	700 (214)	0-151 ft 8¾ in	151-700 ft open hole	125-135 170;230; 360-370; 495	ss sh & coal	3209.32 (978.83)
Ponoka	02	08	43	25	W4	Ba	January 1964-R	223 (68)	0-103 ft 5½ in	103-223 ft open hole	125-215	ss	2678.92 (817.07)
Purple Spring	13	07	10	14	W4	An	October 1964-R	15 (5)	0-? ft 12 in			sd & grl	2665 (812.82)
Redwater #1	12	09	57	20	W4	Bn	January 1974-R	170 (52)	0-163 ft 8 5/8 in screen sand pack	163-170 ft #70 slot 161-168	92-130 130-150 grl	sd sd & grl	2036.37 (621.10)
Redwater #2	06	09	57	20	W4	Bn	January 1974-R	87 (27)	0-87 ft 5½ in	slotted	15-40 40-87	sd grl	1954.07 (595.60)
Sherwood Park	08	22	52	23	W4	Ba	Oct. 1960- June 1977	220 (67)	0-90 ft 4½ in	90-220 ft open hole	134-141 182-185 195-198	ss ss ss	2440 (743.7)
Sion #2	01	08	57	01	W5	Bn	May 1972-R	178 (54)	0-170 ft 4½ in	171-178 ft sand fill 170-171 gravel fill	170-178	coal & sh	2345.14 (715.27)

Appendix A (continued)

Well Name	Location Lsd.	Sec.	Tp.	R.	Mer.	Type of[1] Water Level	Period of[2] Record	Depth ft (m)	Well Construction casing	completion	Permeable Interval (ft)	Material	Ground Elevation ft (m)
Sion #3	01	08	57	01	W5	Bn	May 1972-R	33 (10)	0-33 ft 4½ in	28-32 ft slotted csg 28-33 ft 3¾ in, #7 slot screen sand pack- ed	28-33	silt	2345.01 (715.23)
Stettler #6	05	05	39	19	W4	Ba	June 1957-R	160 (49)	0-? ft 5½ in		49-61 61-25 126-132	ss sh & ss ss	2679.30 (816.65)
Stettler 1960-4	13	01	39	20	W4	Ba	March 1961-R	215 (66)	0-43 ft 5½ in	43-215 ft open hole ?	43-25	sdy sh & ss	2700.89 (823.23)
Stettler 1962-4	14	33	38	20	W4	Ba	July 1963-R	220 (67)	0-200 ft 4½ in	200-210 ft screen	193-199 199-210	sd grl	2684.25 (818.16)
Streeter Basin #M4495	08	27	13	01	W5	An	Nov. 1966- March 1981	20 (6)	0-20 ft 4½ in	?	?	slst	4495 (1370.9)
Streeter Basin #W4560	04	27	13	01	W5	An	Nov. 1966- March 1981	29 (9)	0-28 ft 4 in	?	?	fine ss	4560 (1390.8)
Taber (Lake)	04	15	10	16	W4	Aa	October 1961-R	15 (5)	0-? ft 12 in iron culvert	?	10-13	coarse sd	2630 (802.15)
Tri Creek Basin Wampus Cr. #5 of #4	14	10	48	23	W5	Bn	1969-R	350 (107)	0-21 ft 5½ in	21-350 open hole	20-26; 110-112 120-160; 200-214 300-310	ss ss ss	4575 (1395.37)
Tri Creek Basin Wampus Cr. #7a	01	05	48	23	W5	Bn	1969-R	188 (57)	0-8 ft 8½ in	8-188 ft open hole	28-70 87-93 132-188	ss ss ss & sdy sh	4670 (1424.3)
Tri Creek Basin Wampus Cr. #7b	01	05	48	23	W5	Bn	1969-R	73 (22)	0-12 ft 8½ in	12-73 ft open hole	47-65	ss & sdy sh	4675 (1425.8)
Two Hills - Hospital	13	32	54	12	W4	Ba	April 1960-R	300 (92)	0-50 ft 8½ in	50-300 ft open hole	107-120 188-222	ss ss	2014.8 (614.52)
Two Hills - Farm	05	11	54	13	W4	Ba	September 1962-R	180 (55)	0-106 ft 4½ in	106-108 ft open hole	110-156	ss	2019.55 (615.56)

Well Name	Location Lsd.	Sec.	Tp.	R.	Mer.	Type of[1] Water Level	Period of[2] Record	Depth ft (m)	Well Construction casing	completion	Permeable Interval (ft)	Material	Ground Elevation ft (m)
Wainwright - Town	06	31	44	06	W4	Ba	July 1963-R	220 (67)	0-? ft 4½ in	?	140-215	ss	2218.02 (676.07)
Wainwright - Form #1	13	20	43	06	W4	Ba	April 1974-R	440 (134)	0-350 ft 4½ in 350-415 ft 3 in	415-426 ft 3 in screen	422-437	grl	2247.60 (685.07)
Wainwright - Form #2	13	20	43	06	W4	Ba	April 1974-R	62 (19)	0-57 ft 4½ in	57-62 ft #25 slot screen	42-62	sd	2247.64 (685.08)
Waterton Dam #1	09	23	04	28	W4	Ba	October 1964-R	39 (12)	0-39 ft 4½ in	3-39 ft slotted	2.6-39.3 ft	till	3897.35 (1188.7)
Waterton Dam #5	13	19	04	27	W4	Ba	May 1965-R	40 (12)	0-40 ft 4½ in	4-40 ft slotted	3.6-39.6	till	3853.75 (1175.4)
Wetaskiwin No. 26	12	01	46	24	W4	Ba	April 1960-R	211 (64)	0-60 ft 8 5/8 in	60-211 ft open hole	60-211	sdy sh	2404.14 (760.71)
Wetaskiwin 1962-2	14	19	46	23	W4	Ba	July 1963-R	180 (55)	0-57 ft 4½ in	57-180 ft open hole	98-123	ss & sdy sh	2473.66 (754.46)

A = Water-table level; B = Hydraulic-head level; n = natural level; a = influenced by production of groundwater; R = Recording at end of 1981.

Appendix B List of groundwater observation wells in the Alberta network*

Wells monitored by Alberta Environment (Wr) (Provincial network) July 4/85

Location LS-SEC-TP-R-MER	Name	Start or Record	Well Depth m	Depth to Water m	Elevation Top of casing m	Production Interval m	Completion Type	Aquifer Lithology, Name, Remarks
SW-31-01-11-W4	Aden	1985	180	10.755	950	120-180	Open	ss, Milk River
14-11-01-22-W4	Del Bonita 70-3	1985/6	73.2	8.8		26.5-73.2	Open	ss, Blood Reserve, T = 40, Q_{20} = 420
04-08-02-02-W4	Cressday 85-2	1985	80	21		76.8-80	Screen	ss, Belly River, T = 7.3, P = .17, Q_{20} = 146*
14-24-02-15-W4	Milk River	1956	7.6	3.3	991.46	0-7.6	Open	sd
05-13-06-08-W4	Pakowki Lake 85-1	1985	69.0	23		65.9-69	Screen	sd, Medicine Hat Valley, T = 72, P = .1, Q_{20} = 27

Appendix B (continued)

Location LS-SEC-TP-R-MER	Name	Start or Record	Well Depth m	Depth to Water m	Elevation Top of casing m	Production Interval m	Completion Type	Aquifer Lithology, Name, Remarks
13-19-04-27-W4	Waterton #5	1963	12.0	2.9	1189.3	0.8-12.0	Slotted	till
02-04-07-02-W4	Cypress 85-1	1985	30.0	16		27-30	Screen	ss, Upper Bearpaw sandstones, T = 72, P = .5, Q_{20} = 370
12-08-08-02-W4	Cypress Hills 2293E	1984	14.4	12.2		12.8-14.4	Screen	sd + gr
06-24-08-03-W4	Elkwater Lake 2294E	1984	33.5	11		32-33.5	Screen	sd + gr, t = 9.9, P = .007, Q_{20} = 84
10-09-08-21-W4	Lethbridge	1962	18.7	2	915.12	16.5-21	Screen	sd
04-13-08-21-W4	McNally	1962	76.2	27.4	908.8	74.7-76.2	Screen	Sask, sd + gr
01-15-09-25-W4	Orton 1514E	1984	50.3	19.94		44.5-50	Slotted	sd + gr
04-30-09-26-W4	Mud Lake 1538E	1985	33.8	3.6		27.1-33.8		gravel
16-33-11-22-W4	Keho Lake 2019E	1982	27.0	23.7	963.21	25.5-27.0	Screen	gravel
16-10-12-04-W4	Ross creek 2286E	1984	73.7	5.94		67.7-73.7	Machine slotted	sd, t = 5, P = 7.6^{-4}, Q_{20} = 107
16-10-12-04-W4	Ross Creek 2288E	1984	36	5		32.9-36	Screen	sd
10-23-12-05-W4	Medicine Hat	1960	21.3	7.5	660.0	3-21.3	Slotted	gravel
SE-16-12-23-W4	Barons 615E	1971	19.8	3.2	964.77	6.1-19.8	Open	ss
07-05-15-09-W4	Suffield 85-1	1985	111.3	44		108.2-111.3	Screen	sd, Lethbridge Valley
07-05-15-09-W4	Suffield 85-2	1985/6	59	43.6		57.6-59	Screen	sd
16-23-23-06-W4	Buffalo North 85-2	1985	70.4	59		65.9-70.4	Screen	gravel
16-36-23-17-W4	Gem 66-7	1984	30.5	14		24.4-30.5	Screen	gravel
04-27-25-09-W4	Bigstone 85-3	1985	35.1	24		32-35.1	Screen	gravel
13-24-28-02-W4	Sibbald 85-2	1985	34.5	7.5		31.4-34.5	Screen	sd, Sibbald Valley, T = 77, P = 1.6, S = 5^{-4}, Q_{20} = 884
04-28-29-16-W4	Hand Hills #1	1965	96.01	78.8	1015.03	92.5-96	Open	Edmonton fm (coal) + shale
04-28-29-16-W4	Hand Hills #2	1965	40.54	36.3	1015.18	36.3-38.7	Slotted	Paskapoo ss
04-30-32-28-W4	Olds #147	1967	213	10.2	978.92	46-213	Open	ss, sh, coal
13-21-34-26-W4	Elnora #7	1962	45.72	41.5	1025.19	39.6-45.7	Slotted	sh, ss, coal
09-34-34-26-W4	Elnora #6	1962	9.5	2.5	918.64	3.0-4.9, 7.6-9.4	Slotted	ss, coal, sh

Location LS-SEC-TP-R-MER	Name	Start or Record	Well Depth m	Depth to Water m	Elevation Top of casing m	Production Interval m	Completion Type	Aquifer Lithology, Name, Remarks
16-36-34-26-W4	Elnora #5	1962	13.7	2.2	894.33	9.1-13.7	Slotted	clay
08-18-35-09-W4	Cornation	1958	61	22.0	780.43	48.8-61.6	Open	ss - Bulwark
03-29-35-24-W4	Elnora #2	1962	5.18	2	888.19	3.7-4.3	Slotted	sd
13-10-35-25-W4	Elnora #4	1962	13.72	6	937.53	5.5-7.9, 9.1-13.7	Slotted, Open	sd
12-13-35-25-W4	Elnora #3	1962	18.91	13.8	966.39	9.1-18.9	Slotted	ss
05-06-36-28-W4	Innisfail	1965	28.5	20.3	893.88	27.4-44.2	Open	ss
15-33-38-20-W4	Stettler 1962-4	1963	64.0	17	818.35	61.0-64.0	Screen	ss
05-05-39-19-W4	Stettler #6	1957	40.2	4.5	816.98	14.9-25.9, 38.4-40.2		ss, sh
13-01-39-20-W4	Stettler 1960-4	1961	65.53	14	823.54	13.1-65.5	Open	ss, sh
12-23-41-14-W4	Galahad (RCA 1960-3)	1960	35.4	8.4	704.76	24.4-35.4	Slotted	sd, gr
08-28-42-10-W4	Hardisty 1875E (3B)	1984	63.1	42.4		60-63.1	Screen	Sask gr, $T = 96$, $Q_{20} = 393$
13-20-43-06-W4	Wainwright Farm (811E)	1975	134.11	30.71	685.29	128.6-133.2	Screen	sd, gr
13-20-43-06-W4	Wainwright Farm (812E)	1975	18.59	15.48	685.22	12.8-18.9	Screen	sd
06-01-43-10-W4	Hardisty 1869E (1A)	1984	53.4	4.635		36.58-53.4	Slotted	ss, $T = 2$, $Q_{20} = 45$
07-01-43-10-W4	Hardisty 1881E (2BB)	1984	15.2	2.18		12.2-15.2	Slotted	gr, $T = 450$, $Q_{20} = 2121$
02-08-43-25-W4	Ponoka 60-2	1960	68.0	29	817.23	31.4-68.0	Open	Paskapoo ss
11-31-44-06-W4	Wainwright Town obs. #10	1962	67	25.6	676.15	52-67.0	Open	ss
03-17-44-13-W4	Killam	1963	27.3	2.4	675.54	27.7-29.0	Screen	sd
14-19-46-23-W4	Wetaskiwin #26	1960	64.3	4.9	760.45	18.3-64.3	Open	ss
04-12-46-24-W4	Wetaskiwin 1962-2	1964	55.0	6.5	754.06	15.2-54.9	N/A	Edm. fm. (ss, sdy sh)
02-18-49-23-W4	Rollyview 2317E	1984	50	40		47-50	Open	coal
10-26-49-25-W4	Leduc	1956	22.1	6.0	235.86	7-21.9	Open	
11-01-50-01-W4	Lloydminster	1957	57.91	20.8	645.92	52-57.91		Ribstone ss
08-36-50-26-W4	Devon #1	1960	10.67	6.5	698.98	9.1-10.7	Screen	sd
08-11-51-20-W4	Cooking Lake 1348E	1974	33.5	8.5		28.7-29.6	Screen	sd

Appendix B (continued)

Location LS-SEC-TP-R-MER	Name	Start or Record	Well Depth m	Depth to Water m	Elevation Top of casing m	Production Interval m	Completion Type	Aquifer Lithology, Name, Remarks
08-11-51-20-W4	Cooking Lake 1349E	1974	61.0	20.7		55.2-56.4	screen	coal
08-12-51-26-W4	Devon #2	1965	7.62	2.0	693.295	4.6-7.6	Slotted	sd
09-04-53-24-W4	Capital City Park #1	1975	14	7.9	632.76	7.6-14.3	Open	coal & sd
05-11-53-24-W4	Capital City Park #4	1975	8	6.6	633.37	6.1-7.9	Screen	sd
05-11-53-24-W4	Capital City Park #5	1975	26	5.9	633.37	10.7-26.6	Open	ss & coal
06-12-53-24-W4	Capital City Park #3	1975	10	7.6	632.76	8.8-10.0	Open	coal & ss
16-01-53-24-W4	Capital City Park #6	1975	38	16.5	632.76	15.2-38.1	Open	ss & coal
07-14-53-26-W4	Wagner 2238E	1984	15.5	1.3		14-15.5	Screen	sd
12-32-54-12-W4	Two Hills Hospital	1960	33.2	11.5	612.56	15.2-33.2	Open	ss
05-11-54-13-W4	Two Hills Farm	1962	54.86	11	615.60			ss
11-09-57-20-W4	Redwater #2	1974	28.96	9.2	595.64			Sask, sd, gr
12-09-57-20W4	Redwater #1	1974	60.96	34.6	620.90	48.8-51.2 51.8-61.0	Slotted Open	Sask, sd, gr
08-10-58-22-W4	Opal 2044E	1984	182.9	11.4		172.9-182.9	Open	ss, 5.58″
01-26-60-08-W4	Glendon 80-W1	1985/6	89.0	34		74-89.0	Screen	sd & gr, 7″, T=440, S=3.4-03
11-15-62-05-W4	Bonnyville 1708EA (east)	1977	43.6	21	551.279	43.6-45	Screen	sd
11-15-62-05-W4	Bonnyville 1708EB (west)	1977	76.2	27.7	551.239	73.2-76	Screen	sd
15-25-63-05-W4	Lessard 2091E	1985	135	18.49	592.783	129-135	Screen	sd, 10.75″ + 7″ casing
04-27-63-07-W4	Iron River 2078E	1982	60	10.61	564.474	52.7-57	Screen	sd
04-27-63-07-W4	Iron River 2079E	1982	101	8.51	564.351	96-101	Screen	sd T=7.7
13-30-64-03-W4	Esso TH-2	1985/5						
03-27-64-11-W4	Rich Lake 2094E (south)	1985/5	114	37.17	581.880	104-114	Screen	sd, 7″
03-27-64-11-W4	Rich Lake 2095E	1985/5	84.7	33.75	582.380	78.7-84.7	Screen	sd, 7″
SW-09-65-02-W4	Marie Lake 82-1	1982	144.8	48.06	593.263	140-144.8	Screen	sd
SW-09-65-02-W4	Marie Lake 82-2 (west)	1982	72.5	47.03	593.290	68-72.5	Screen	sd

Location LS-SEC-TP-R-MER	Name	Start or Record	Well Depth m	Depth to Water m	Elevation Top of casing m	Production Interval m	Completion Type	Aquifer Lithology, Name, Remarks
04-26-65-04-W4	Bourque Lake 1772E (south)	1978	166	31.5	616.542	161-166	Screen	sd
04-26-65-04-W4	Bourque Lake 1947E (north)	1980	95	22.5	616.462	92-95	Screen	sd, $T=7.7$, $Q_{20}=2480$
04-26-65-04-W4	Bourque Lake (7″) 83-1	1985	172.8	25.40	610.392	154.1-172.8	Screen	sd 7″, $T=417$, $S=2.8\text{-}04$, $Q_{20}=17{,}000$
SW-28-66-05-W4	BP-Triad	1983	126	10.7	648	121-126	Screen	sd
10-22-67-05-W4	Wolfe River 84-1	1984	140.8	23.64	665.298	136-140.8	Screen	sd
10-22-67-05-W4	Wolfe River 84-2	1984	48.7	3.36	665.48	45.7-48.7	Screen	sd
02-32-68-05-W4	Fisher Creek 84-2	1984	154	41.49	692.406	151.8-154	Screen	sd
02-32-68-05-W4	Fisher Creek 84-3	1984	124	40.09	692.208	120.4-124	Screen	sd
02-32-68-05-W4	Fisher Creek 84-4	1984	139	41.19	692.428	131.7-139	Screen	sd
11-10-74-08!W4	Petro Canada Kirby Lake	1983	244	39.5		235-244	Screen	fine sd
15-34-77-15-W4	House River 2193E	1983	116	+3.6		110-116.4	Screen	sd (7″)
15-34-77-15-W4	House River 2194E (NE)	1983	88	+3.4		82.9-85.95	Screen	sd (5.56″)

* Units $T=m^2/day$; $P=cm/sec$; $Q_{20}=m^3/day$

12-08-07-01-W5	Cowley	1977			1210.4			
14-11-23-09-W5	Marmot Creek Basin S5250	1964	8.5	3	1601.4			gr
03-14-23-09-W5	Marmot Creek Basin S5430	1964	7.93	36	1652			till
06-15-23-09-W5	Marmot Creek Basin S5457	1964	36.58	7.6	1669.1			till
06-15-23-09-W5	Marmot Creek Basin S6170	1964	14.33	14	1870.0			till
11-22-23-09-W5	Marmot Creek Basin N6770	1964	11.58	36	2051.62			Fernie sh
12-15-35-02-W5	Dickson Dam 4015A	1983	20	15.5	955.51	18.1-19.8	Screen	gr

Appendix B (continued)

Location LS-SEC-TP-R-MER	Name	Start or Record	Well Depth m	Depth to Water m	Elevation Top of casing m	Production Interval m	Completion Type	Aquifer Lithology, Name, Remarks
16-26-35-02-W5	Dickson Dam 4026	1983	21	3.5	954.57	18.1-19.8	Screen	gr
10-33-35-03-W5	Dickson Dam 82-1	1983	32	9.8	950.30	30.5-32	Screen	ss
01-22-42-01-W5	Gull Lake	1964	223.5	33.7	900.6	91.44-223.42	Open	sh, ss
12-10-48-03-W5	Warburg 2178E	1984	158.5	56.9	847.21	134.1-158.5	Open	ss, sh
12-10-48-03-W5	Warburg 2179E	1984	85.4	52.7	847.22	69.5-85.4	Open	ss, sh
12-10-48-03-W5	Warburg 2180E	1984	21.3	1.7	847.17	8.5-21.3	Open	ss, sh
12-10-48-03-W5	Warburg 2181E	1984	5.2	0.8	847.22	3.7-5.2	Screen	sd
12-10-48-03-W5	Warburg 2190E	1984	64.9	19.3	847.43	43.9-64.9	Open	ss, sd
14-04-48-02-W5	Warburg 2185E	1984	17.7	9.2	850.95	11.6-17.7	Open	ss, sh
14-04-48-02-W5	Warburg 2187E	1984	125.0	52.75	851.33	94.8-125.0	Open	ss, sh
14-04-48-02-W5	Warburg 2188E	1984	67.1	25.1	851.92	50.3-67.1	Open	ss, sh
14-04-48-02-W5	Warburg 2189E	1984	24.1	1.6	836.10	6.1-24.1	Open	ss, sh
14-04-48-02-W5	Warburg 2196E	1984	30.5	15.8	851.43	21.3-30.5	Open	ss, sh
14-04-48-02-W5	Warburg 2197E	1984	9.1	4.5	851.06	3.1-9.1	Open	ss, sh
16-18-48-08-W5	Drayton Valley	1960?	47.6	14.5	909.56	27.43-60.96	Open	ss
01-05-48-23-W5	Tricreek Basin #7a	1969	57.30	3.0	1425.1	2.44-57.3	Open	ss, sh
01-05-48-23-W5	Tricreek Basin #7b	1969	22.25	5.1		3.66-22.25	Open	ss, sh
03-15-48-23-W5	Tricreek Basin #50bs#4	1969	106.68	15.9	1396.5	6.40-106.68	Open	ss
15-17-53-01-W5	Hubbles Lake 1920E	1980	74.6	33.4		71.6-74.6	Screen	sd
15-17-53-01-W5	Hubbles Lake 1922E	1980	83.8	40.5		77.4-83.8	Slotted	ss, sh
06-20-53-07-W5	Entwistle	1961	33.0	14.0	782.41	N/A	N/A	ss
01-22-53-17-W5	Edson	1960	37.80	31.0	905.4	36.27-37.8	Open	sd, gr
01-28-56-08-W5	Paddle River 81-1-D	1983	60.3	19.7	725.6	58.23-59.76	Screen	sd
04-35-56-08-W5	Paddle River 81-5-B	1983	57.3	10.7	714.0	51.8-54.9	Screen	sd
01-08-57-01-W5	Sion #2	1972	51.6		715.08	51.82+	Open	

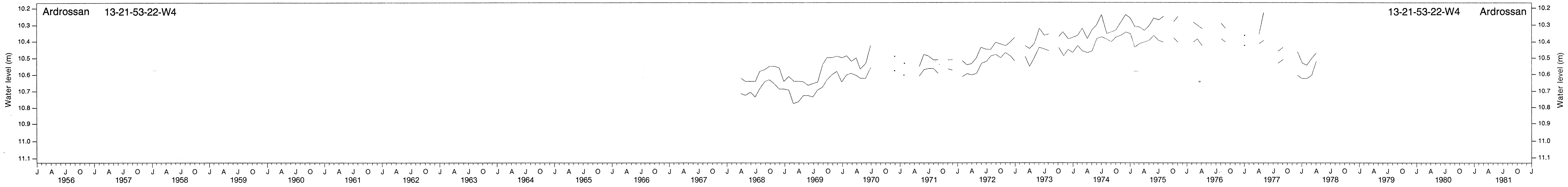
Location LS-SEC-TP-R-MER	Name	Start or Record	Well Depth m	Depth to Water m	Elevation Top of casing m	Production Interval m	Completion Type	Aquifer Lithology, Name, Remarks
01-08-57-01-W5	Sion #3	1972	10.67		714.95	9.14-10.67	Screen	silt
04-28-58-03-W5	Barrhead	1977	86.5		658.50	79.25-87.17	Open	coal
12-31-77-24-W5	Eaglesham 85-1		173.8			170.7-173.8	Screen	sand (7″)
04-29-83-21-W5	West Peace 2099E	1982	12.19	7.9	319.79	10.67-12.19	Screen	gr
01-30-83-21-W5	West Peace 2098E	1982	9.75	4.9	316.79	7.32-8.84	Screen	gr
09-30-83-21-W5	West Peace 2100E	1982	18.0	7.8	319.64	12.73-14.25	Screen	gr
05-29-83-23-W5	Grimshaw Mercier	1965	12.8	4.0	645.4	7.62-17.68	Slotted	gr, Grimshaw
04-13-83-25-W5	Grimshaw Kerndale	1965	36.9	17.4	658.6	27.43-36.87	Slotted	gr, Grimshaw
03-14-83-26-W5	Fairview 8-73	1983	37.5	25.8		34.4-37.2	Slotted	gr, Grimshaw
15-36-71-10-W6	Beaverlodge	1959	35.3	17.8	739.8	23.1-42.7	Open	ss, sh

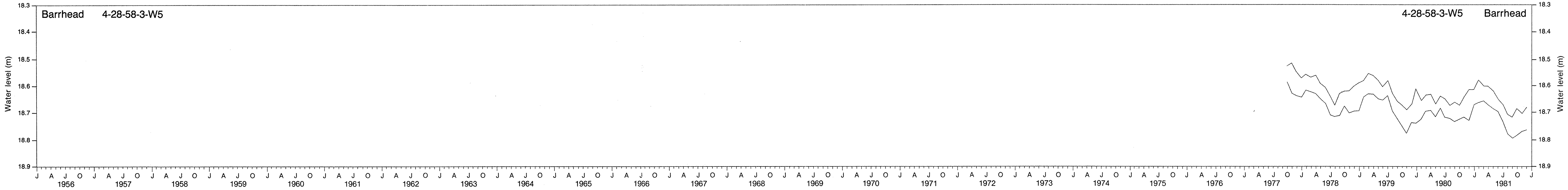
*Updated data on current wells in the Alberta network can be obtained from Alberta Environment.

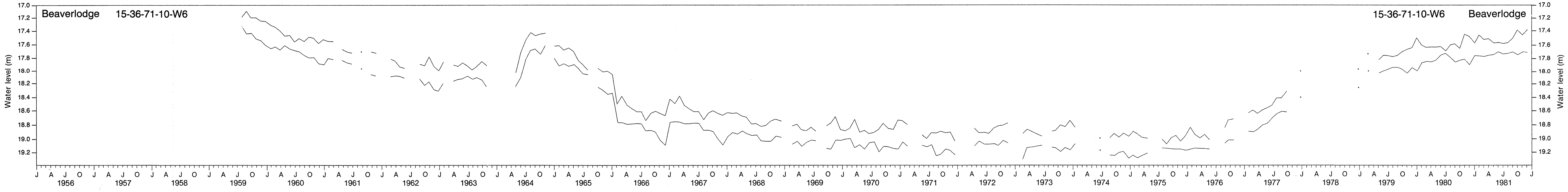
Appendix C. Hydrographs for groundwater observation wells

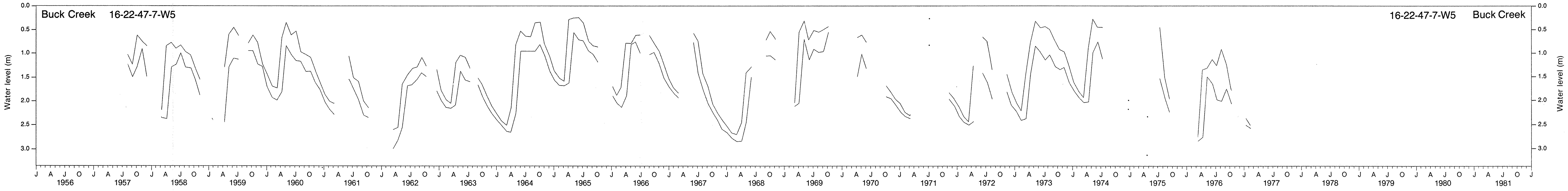
Fold-out section opposite

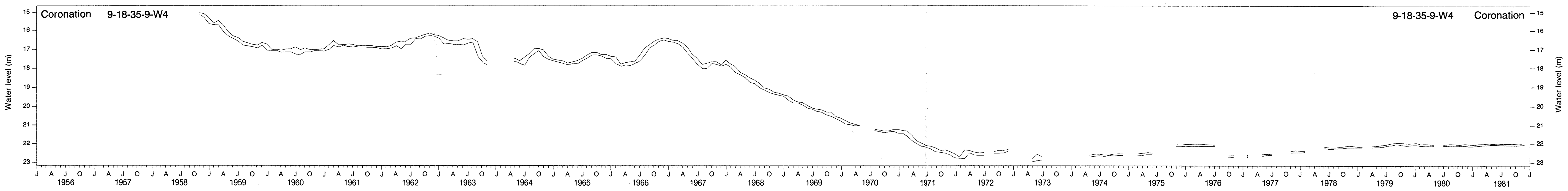
Upper and lower lines represent monthly maximum and minimum water levels respectively.

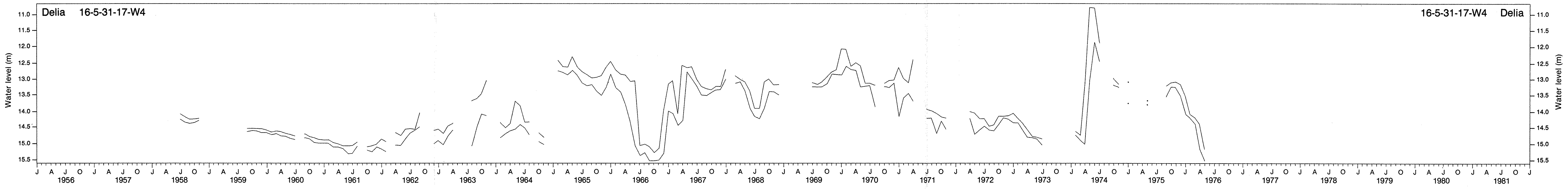

Ardrossan 13-21-53-22-W4
13-21-53-22-W4 Ardrossan
Water level (m)
10.2
10.3
10.4
10.5
10.6
10.7
10.8
10.9
11.0
11.1
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

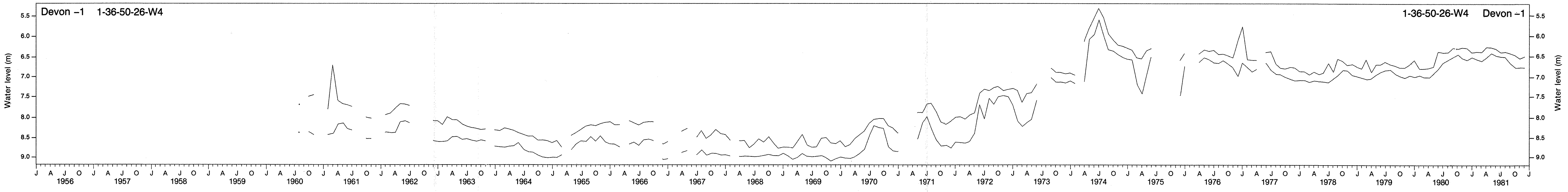

Barrhead 4-28-58-3-W5
4-28-58-3-W5 Barrhead
Water level (m)
18.3
18.4
18.5
18.6
18.7
18.8
18.9
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

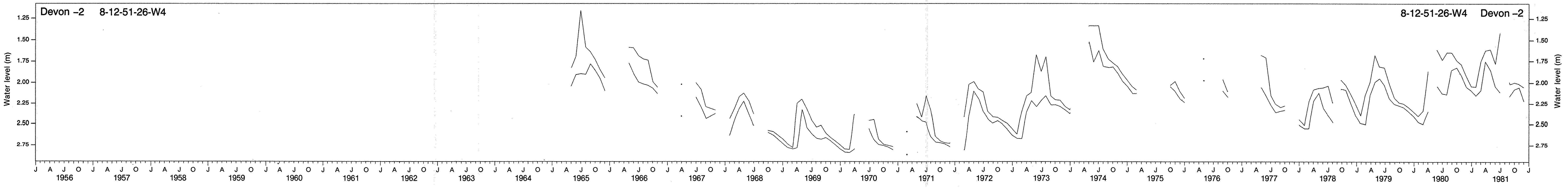

Beaverlodge 15-36-71-10-W6
15-36-71-10-W6 Beaverlodge
Water level (m)
17.0
17.2
17.4
17.6
17.8
18.0
18.2
18.4
18.6
18.8
19.0
19.2
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

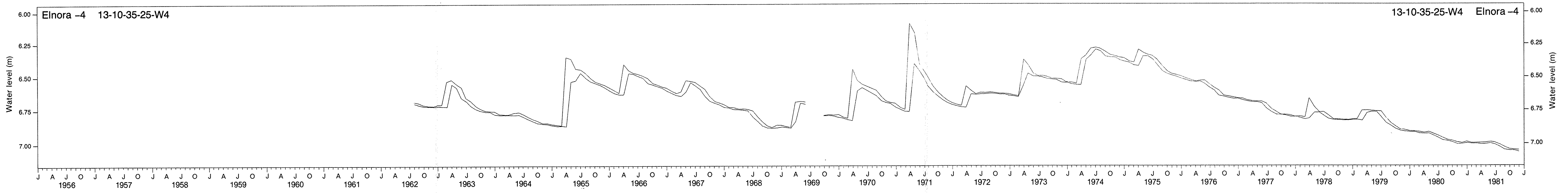

Buck Creek 16-22-47-7-W5
16-22-47-7-W5 Buck Creek
Water level (m)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

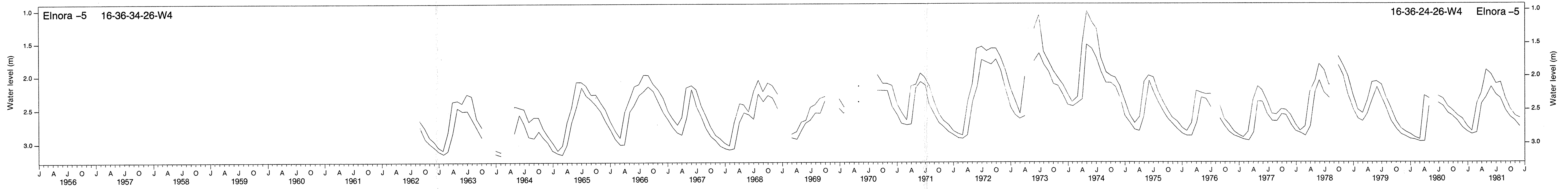

Coronation 9-18-35-9-W4
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

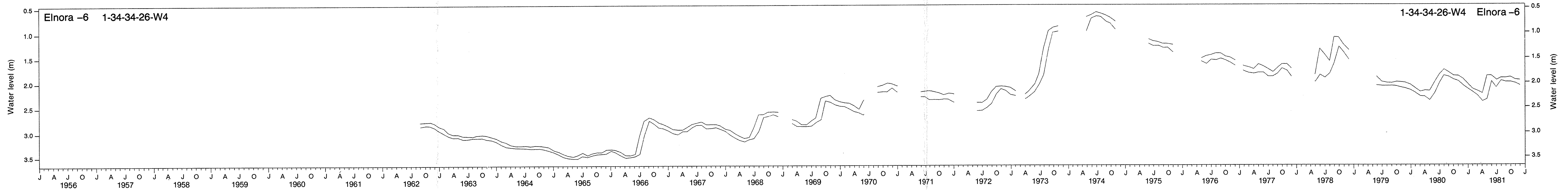

Delia 16-5-31-17-W4
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

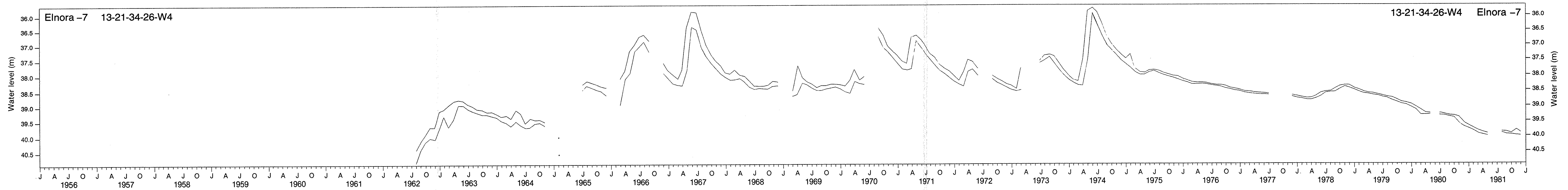

Devon −1 1-36-50-26-W4
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

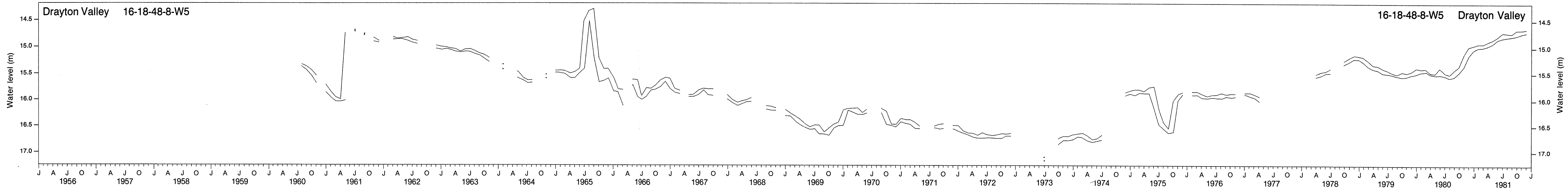

Devon −2 8-12-51-26-W4
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

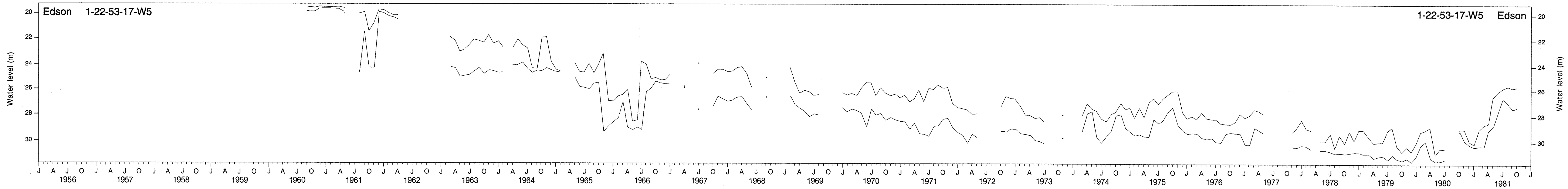

Elnora -4 13-10-35-25-W4
13-10-35-25-W4 Elnora -4
Water level (m)
6.00
6.25
6.50
6.75
7.00
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

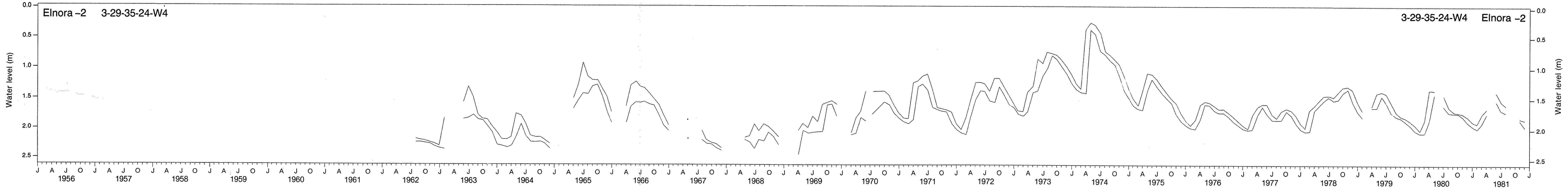

Elnora -5 16-36-34-26-W4
16-36-24-26-W4 Elnora -5
Water level (m)
1.0
1.5
2.0
2.5
3.0
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

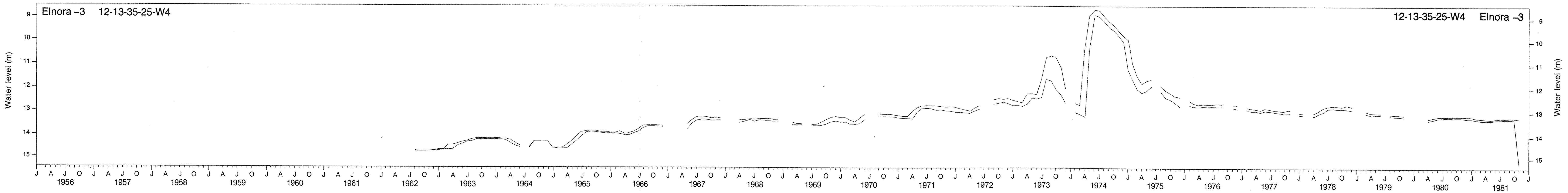

Elnora -6 1-34-34-26-W4
1-34-34-26-W4 Elnora -6
Water level (m)
0.5
1.0
1.5
2.0
2.5
3.0
3.5
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

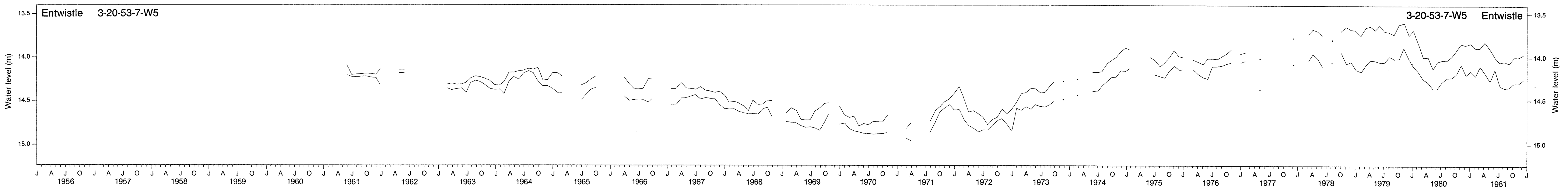

Elnora -7 13-21-34-26-W4
13-21-34-26-W4 Elnora -7
Water level (m)
36.0
36.5
37.0
37.5
38.0
38.5
39.0
39.5
40.0
40.5
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

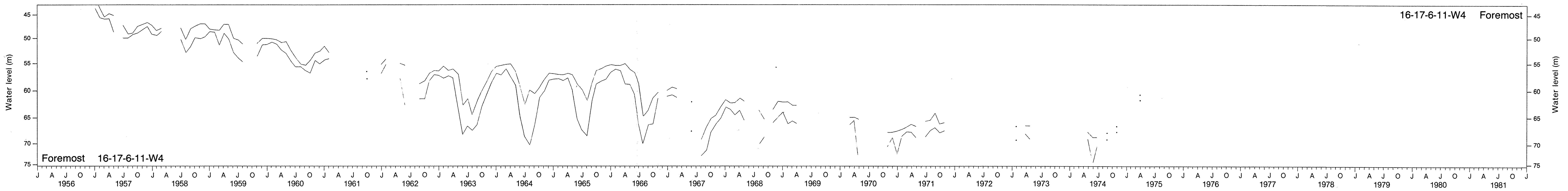

Drayton Valley 16-18-48-8-W5
Water level (m)
14.5
15.0
15.5
16.0
16.5
17.0
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

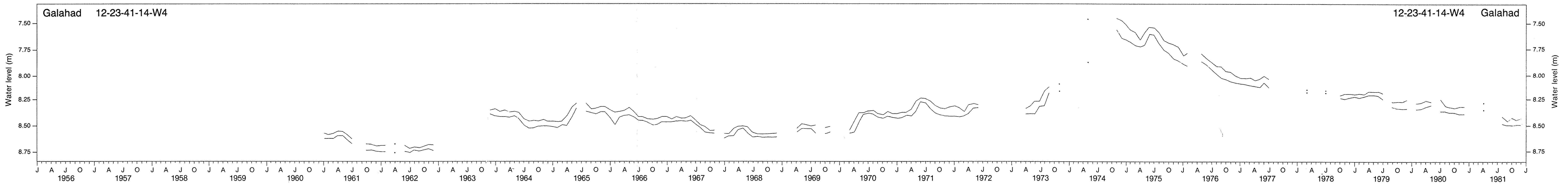

Edson 1-22-53-17-W5
Water level (m)
20
22
24
26
28
30
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

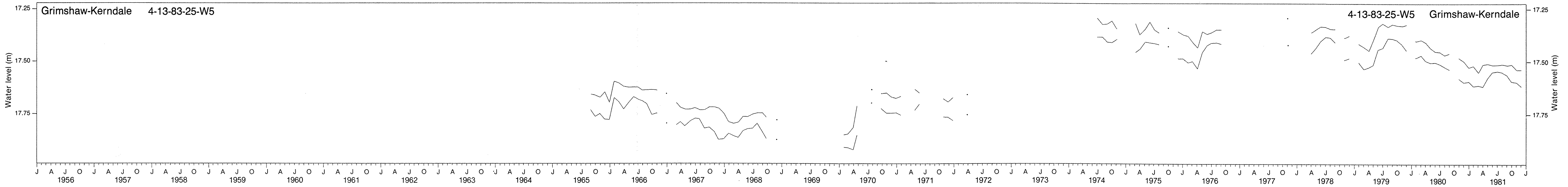

Elnora -2 3-29-35-24-W4
Water level (m)
0.0
0.5
1.0
1.5
2.0
2.5
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

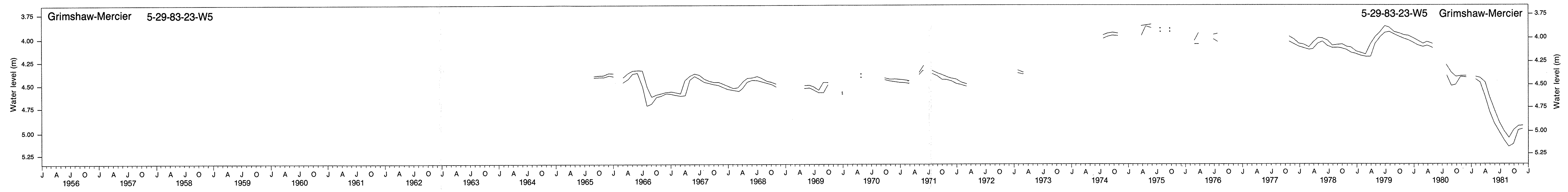

Elnora -3 12-13-35-25-W4
Water level (m)
9
10
11
12
13
14
15
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

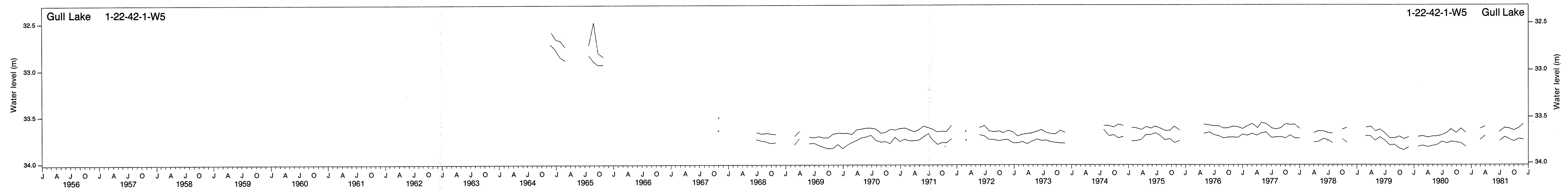

Entwistle 3-20-53-7-W5
3-20-53-7-W5 Entwistle
Water level (m)
13.5
14.0
14.5
15.0
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

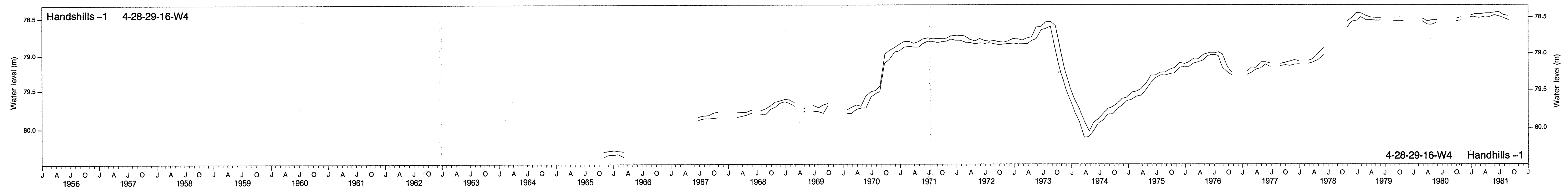

16-17-6-11-W4 Foremost
Foremost 16-17-6-11-W4
Water level (m)
45
50
55
60
65
70
75
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

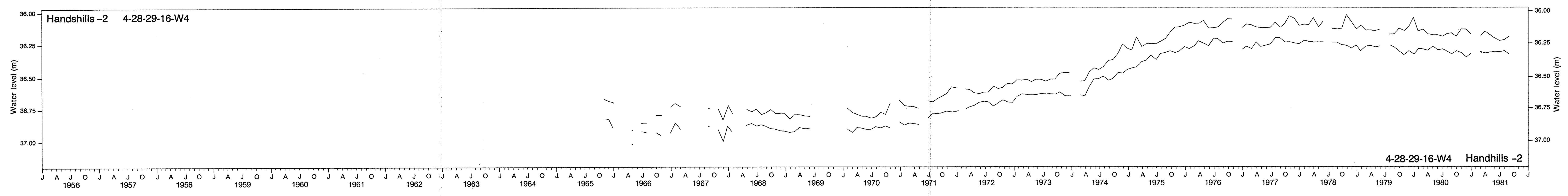

Galahad 12-23-41-14-W4
12-23-41-14-W4 Galahad
Water level (m)
7.50
7.75
8.00
8.25
8.50
8.75
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

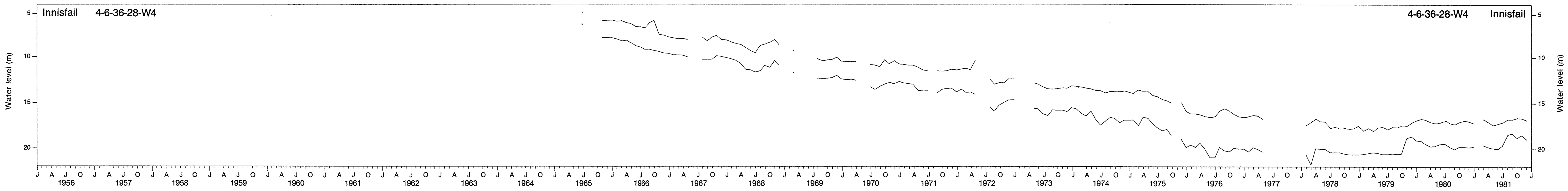

Grimshaw-Kerndale 4-13-83-25-W5
4-13-83-25-W5 Grimshaw-Kerndale
Water level (m)
17.25
17.50
17.75
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

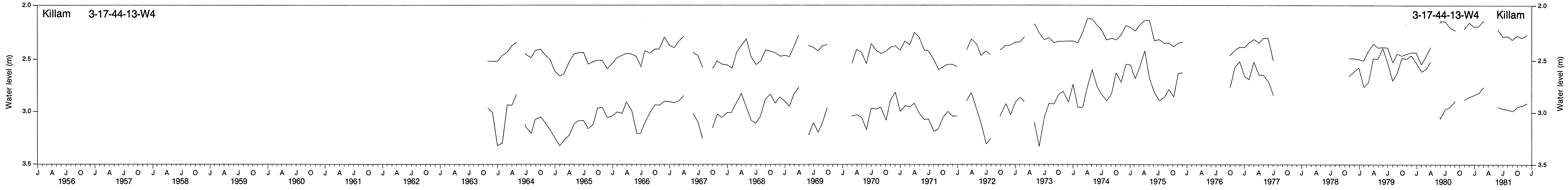

Grimshaw-Mercier 5-29-83-23-W5
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

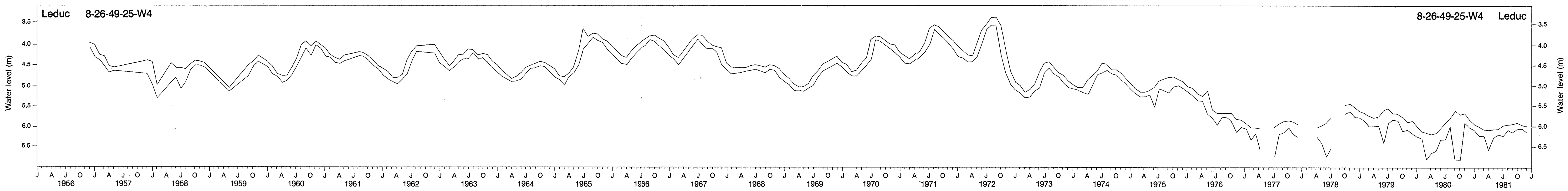

Gull Lake 1-22-42-1-W5
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

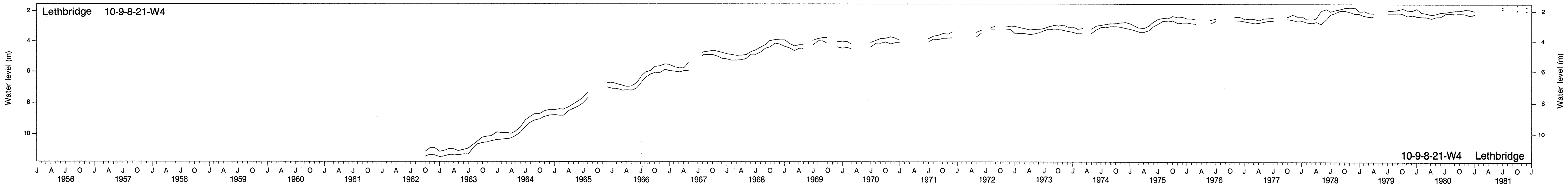

Handshills -1 4-28-29-16-W4
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

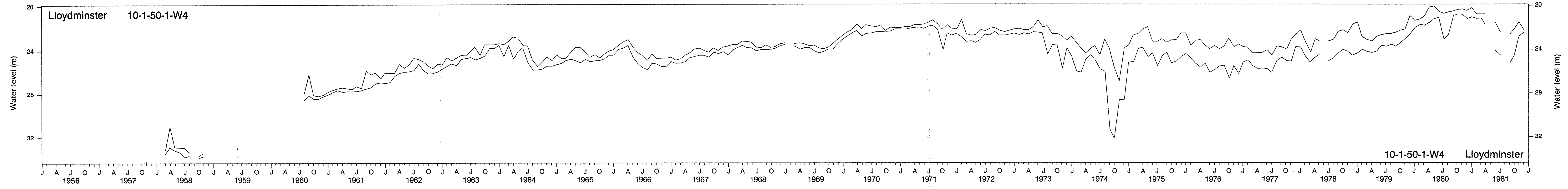

Handshills -2 4-28-29-16-W4
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

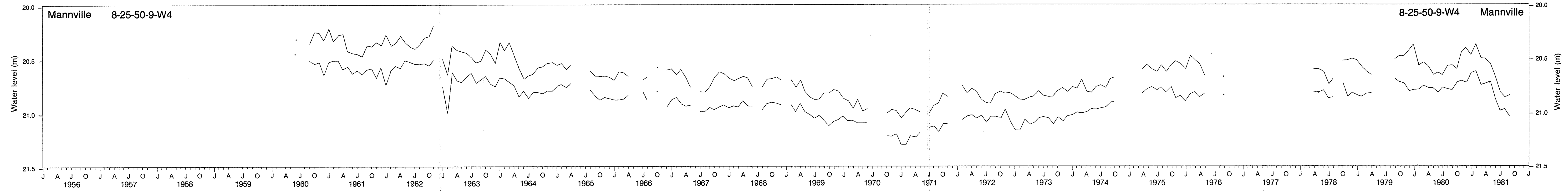

Innisfail 4-6-36-28-W4
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

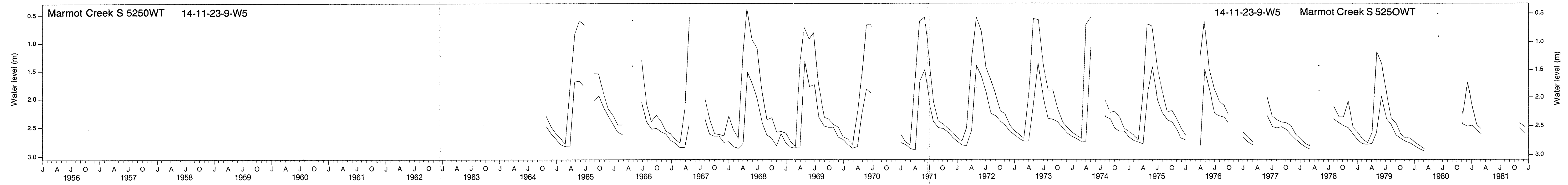

Killam 3-17-44-13-W4
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

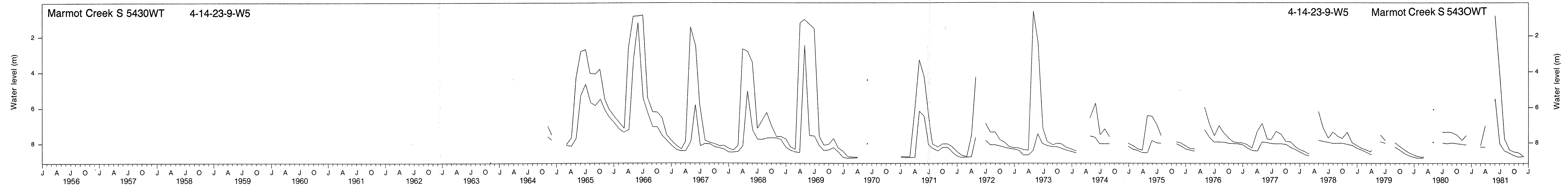

Leduc 8-26-49-25-W4
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

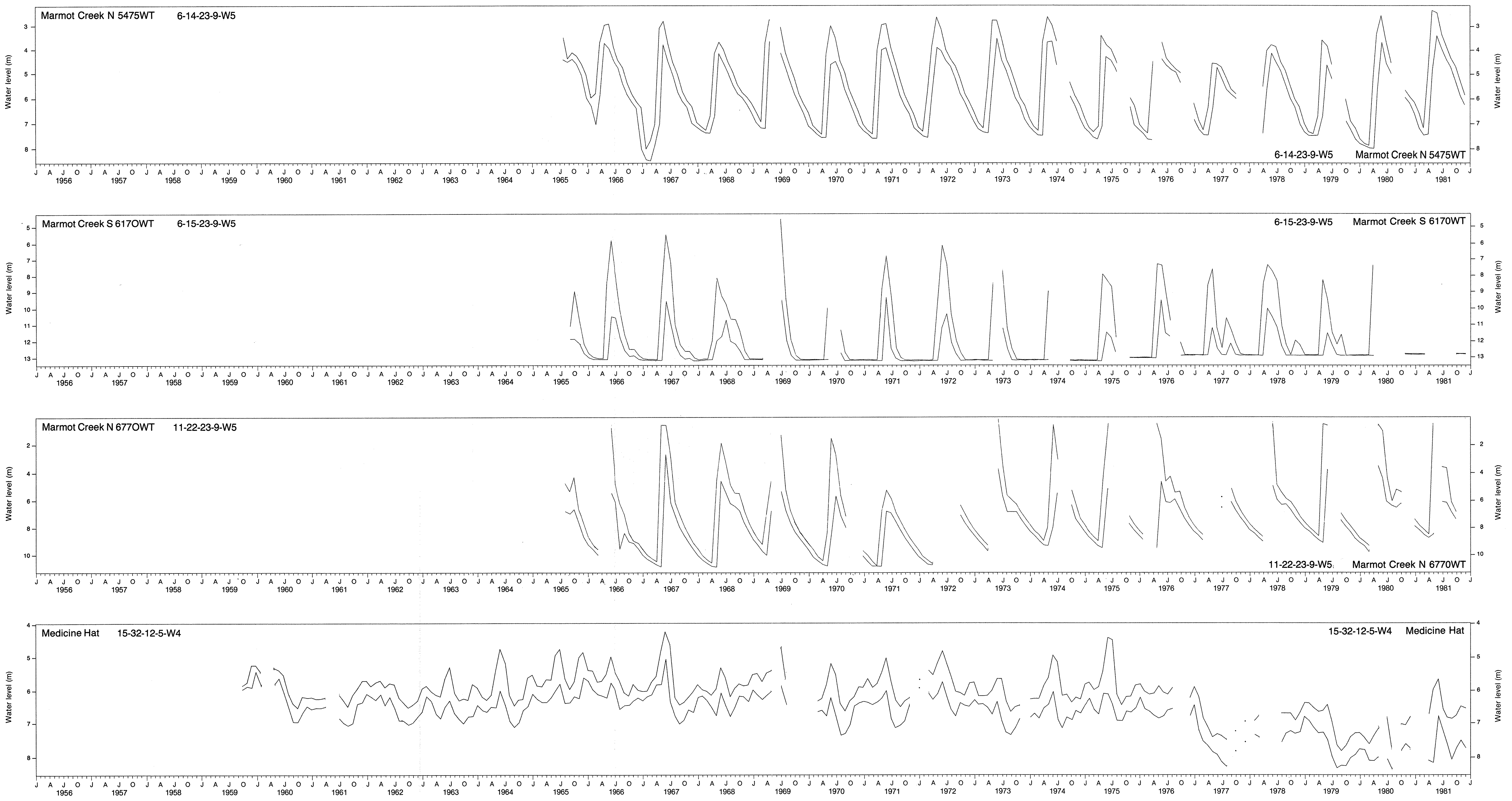

Lethbridge 10-9-8-21-W4
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

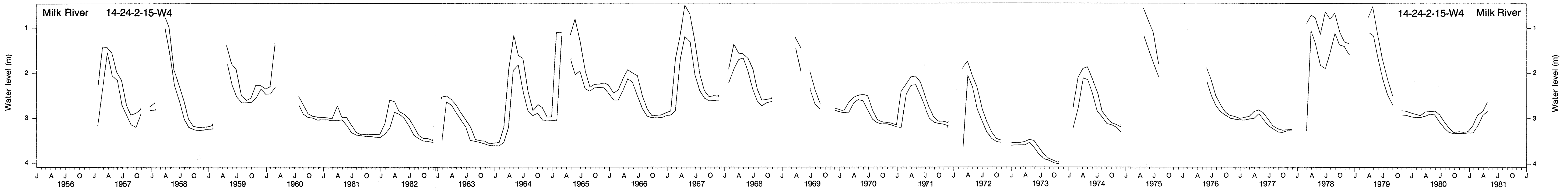

Lloydminster 10-1-50-1-W4
Water level (m)
20
24
28
32
10-1-50-1-W4 Lloydminster
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

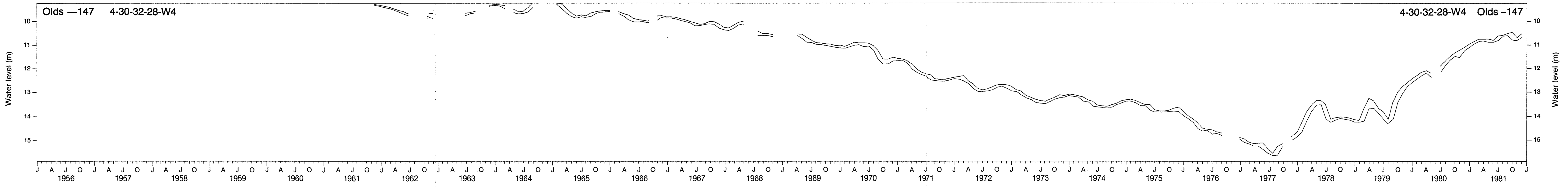

Mannville 8-25-50-9-W4
8-25-50-9-W4 Mannville
Water level (m)
20.0
20.5
21.0
21.5
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

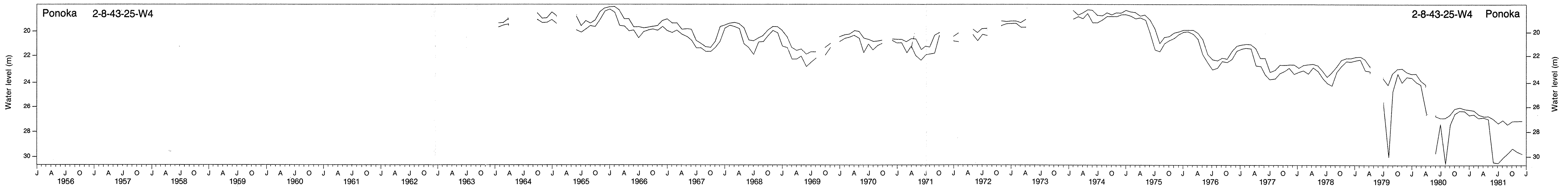

Marmot Creek S 5250WT 14-11-23-9-W5
14-11-23-9-W5 Marmot Creek S 525OWT
Water level (m)
0.5
1.0
1.5
2.0
2.5
3.0
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

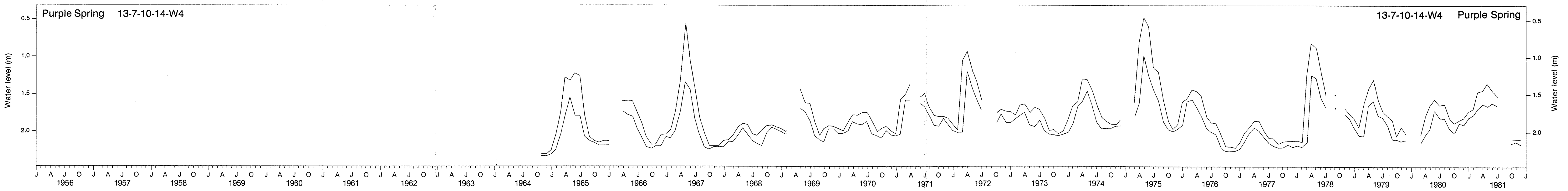

Marmot Creek S 5430WT 4-14-23-9-W5
4-14-23-9-W5 Marmot Creek S 543OWT
Water level (m)
2
4
6
8
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

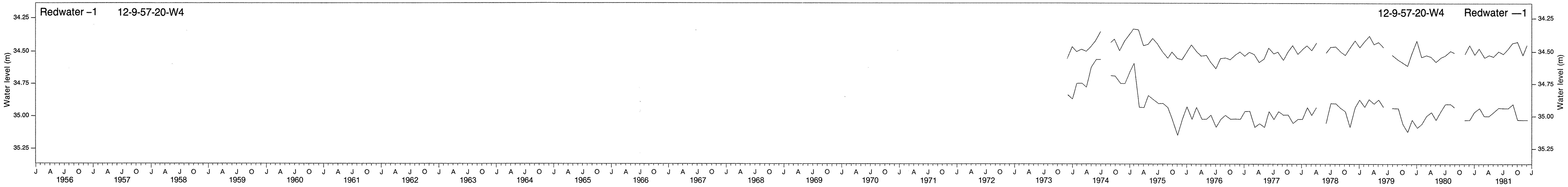

Marmot Creek N 5475WT 6-14-23-9-W5
6-14-23-9-W5 Marmot Creek N 5475WT
Water level (m)
Marmot Creek S 617OWT 6-15-23-9-W5
6-15-23-9-W5 Marmot Creek S 6170WT
Water level (m)
Marmot Creek N 677OWT 11-22-23-9-W5
11-22-23-9-W5 Marmot Creek N 6770WT
Water level (m)
Medicine Hat 15-32-12-5-W4
15-32-12-5-W4 Medicine Hat
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

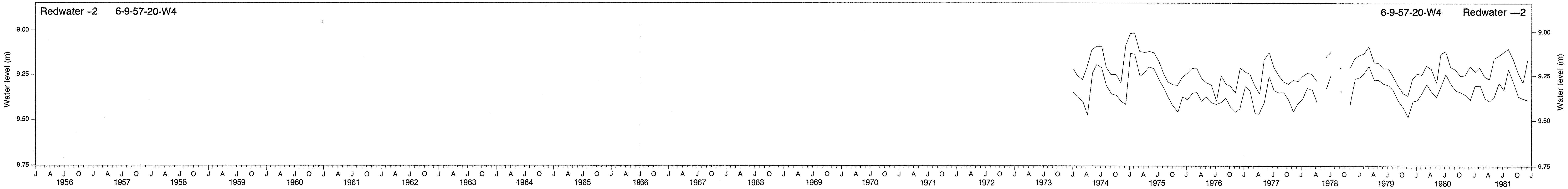

Milk River 14-24-2-15-W4
14-24-2-15-W4 Milk River
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

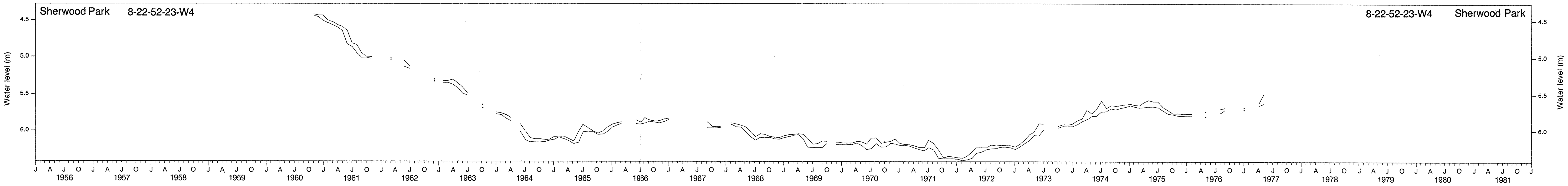

Olds —147 4-30-32-28-W4
4-30-32-28-W4 Olds –147
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

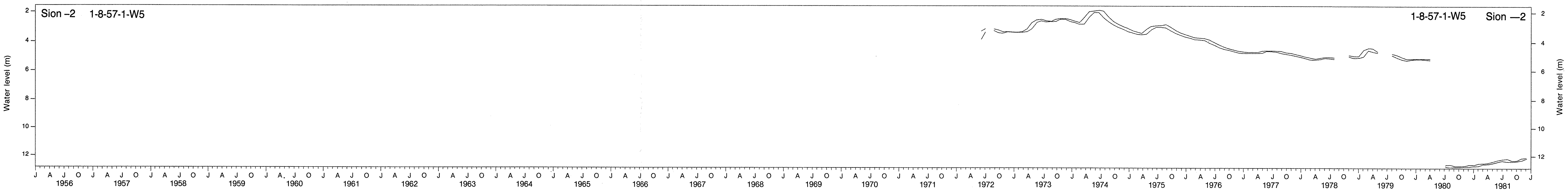

Ponoka 2-8-43-25-W4
2-8-43-25-W4 Ponoka
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

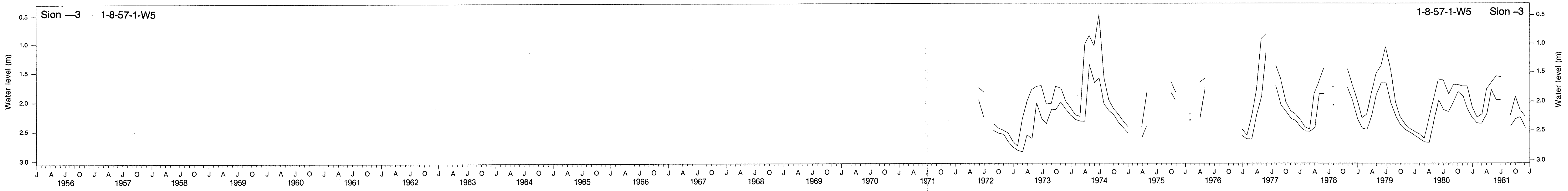

Purple Spring 13-7-10-14-W4
13-7-10-14-W4 Purple Spring
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

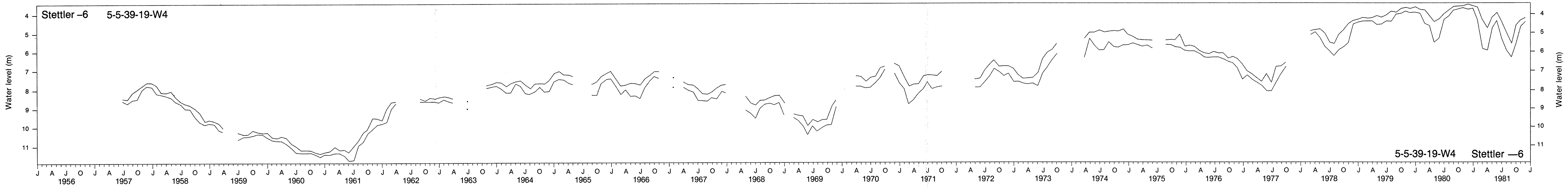

Redwater –1 12-9-57-20-W4
12-9-57-20-W4 Redwater —1
Water level (m)
34.25
34.50
34.75
35.00
35.25
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

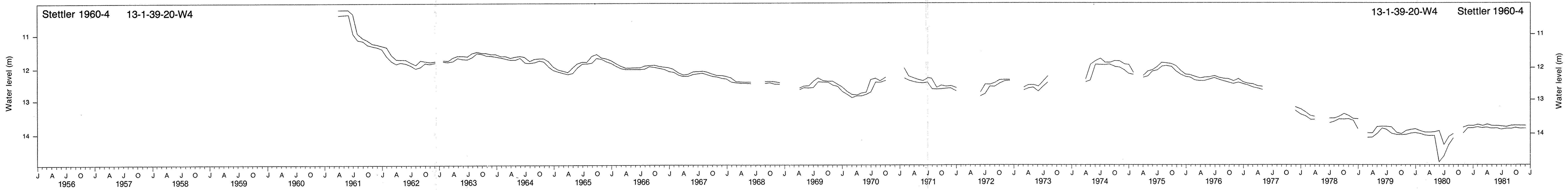

Redwater –2 6-9-57-20-W4
6-9-57-20-W4 Redwater —2
Water level (m)
9.00
9.25
9.50
9.75
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

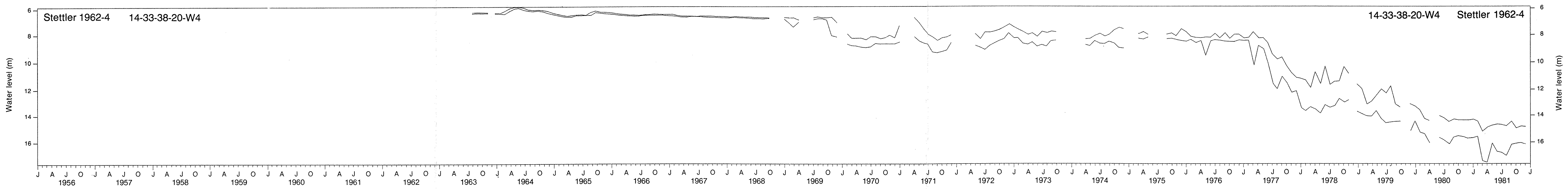

Sherwood Park 8-22-52-23-W4
8-22-52-23-W4 Sherwood Park
Water level (m)
4.5
5.0
5.5
6.0
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

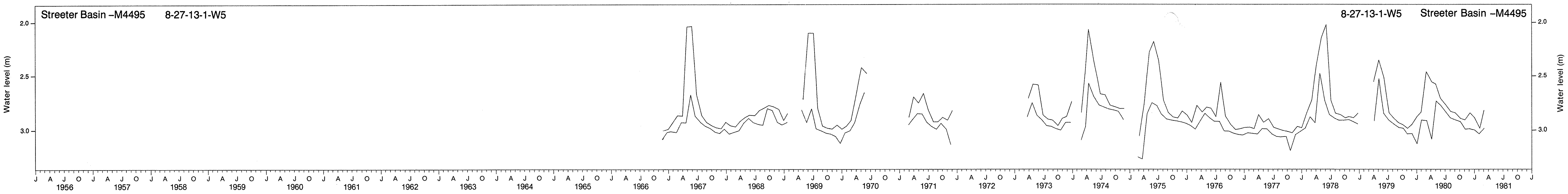

Sion –2 1-8-57-1-W5
1-8-57-1-W5 Sion —2
Water level (m)
2
4
6
8
10
12
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

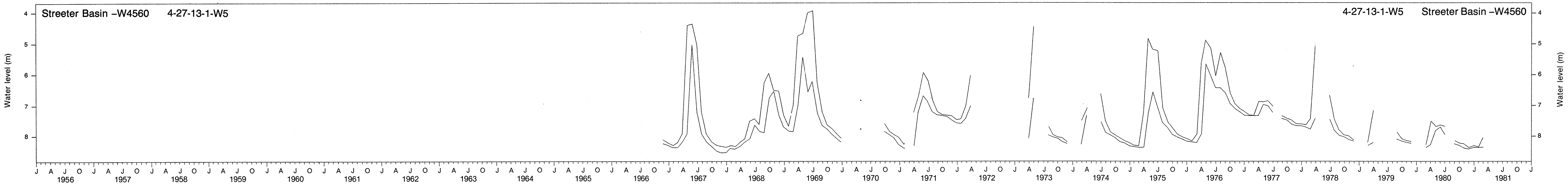

Sion —3 1-8-57-1-W5
1-8-57-1-W5 Sion –3
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

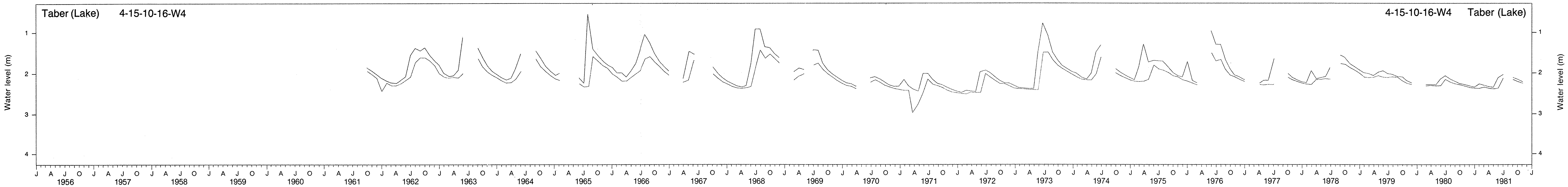

Stettler –6 5-5-39-19-W4
5-5-39-19-W4 Stettler —6
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

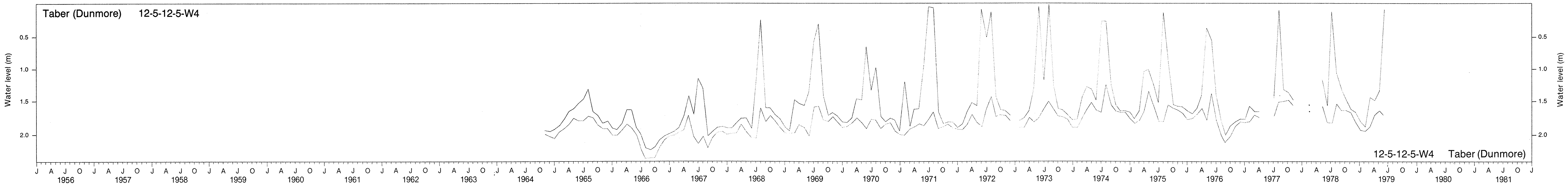

Stettler 1960-4 13-1-39-20-W4
13-1-39-20-W4 Stettler 1960-4
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

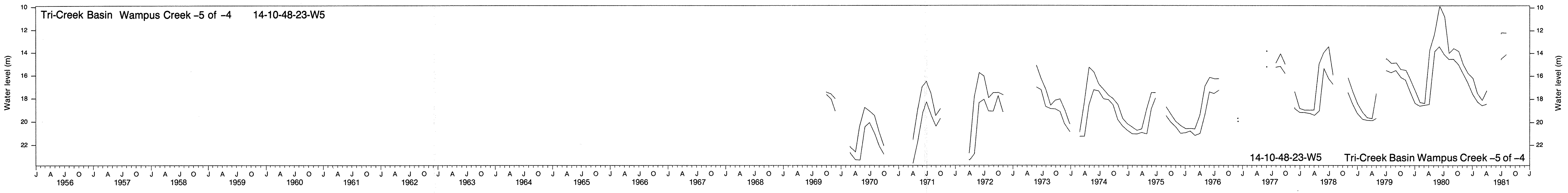

Stettler 1962-4 14-33-38-20-W4
14-33-38-20-W4 Stettler 1962-4
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

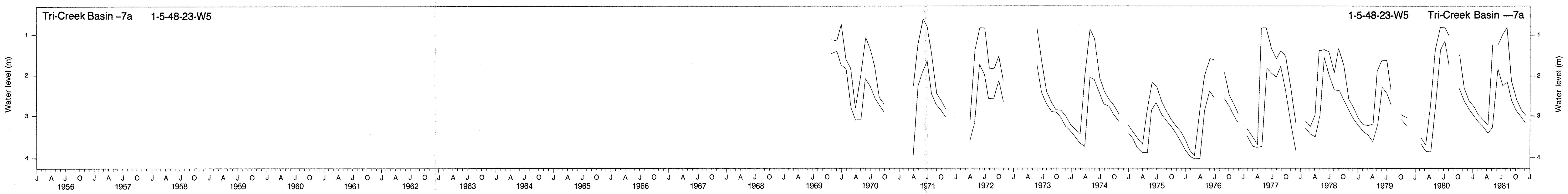

Streeter Basin –M4495 8-27-13-1-W5
Water level (m)
2.0
2.5
3.0
J A J O
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

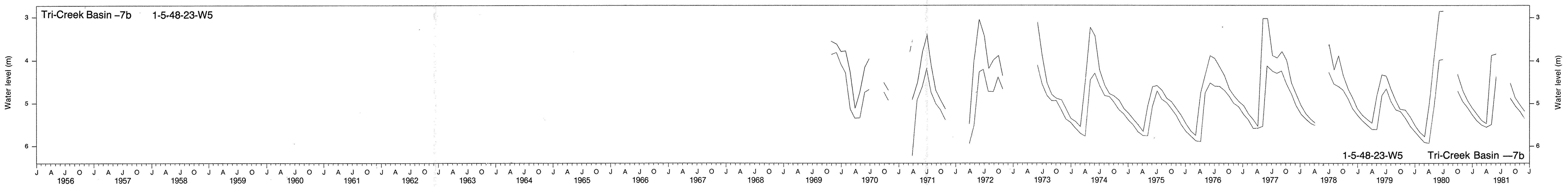

Streeter Basin –W4560 4-27-13-1-W5
Water level (m)
4
5
6
7
8
J A J O
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

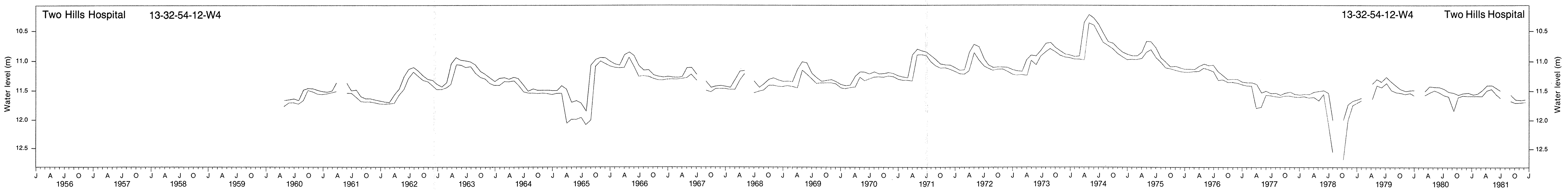

Taber (Lake) 4-15-10-16-W4
Water level (m)
1
2
3
4
J A J O
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

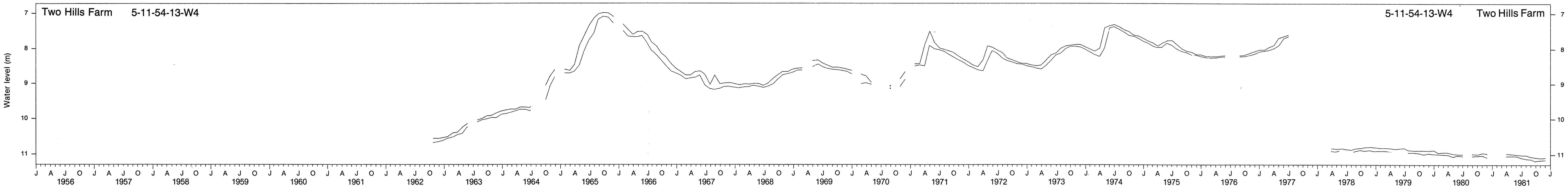

Taber (Dunmore) 12-5-12-5-W4
Water level (m)
0.5
1.0
1.5
2.0
J A J O
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

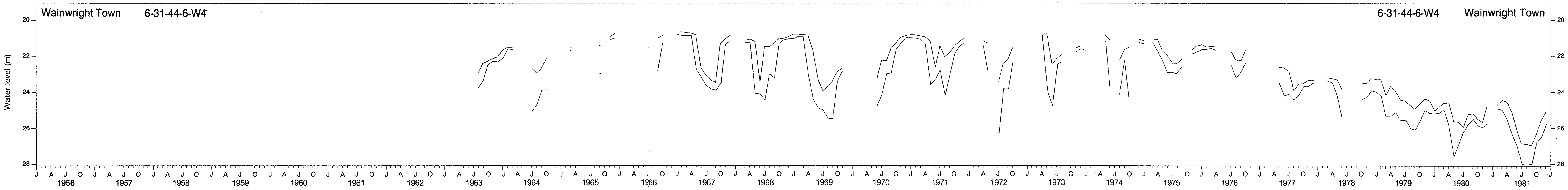

Tri-Creek Basin Wampus Creek -5 of -4 14-10-48-23-W5
Water level (m)
14-10-48-23-W5 Tri-Creek Basin Wampus Creek -5 of -4
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

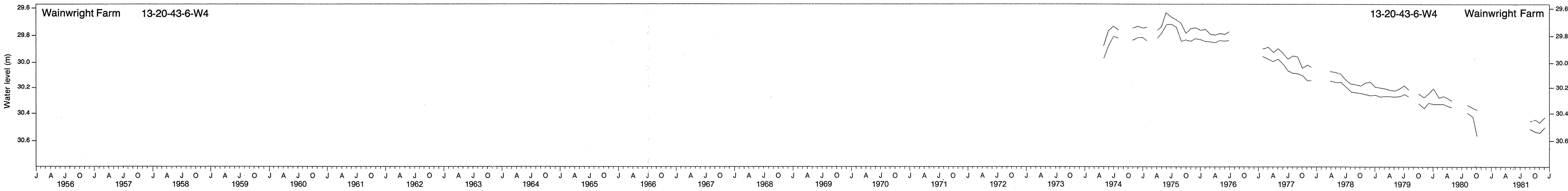

Tri-Creek Basin -7a 1-5-48-23-W5
Water level (m)
1-5-48-23-W5 Tri-Creek Basin —7a
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

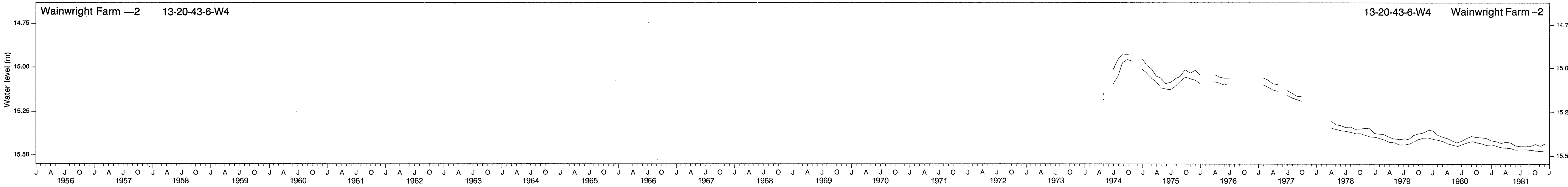

Tri-Creek Basin -7b 1-5-48-23-W5
Water level (m)
1-5-48-23-W5 Tri-Creek Basin —7b
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

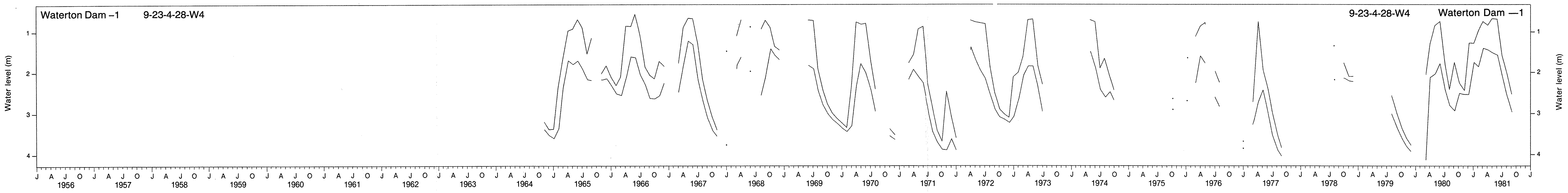

Two Hills Hospital 13-32-54-12-W4
Water level (m)
13-32-54-12-W4 Two Hills Hospital
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

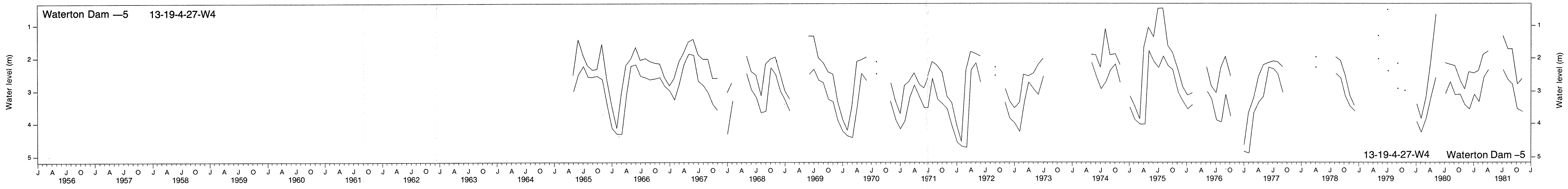

Two Hills Farm 5-11-54-13-W4
Water level (m)
7 8 9 10 11
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

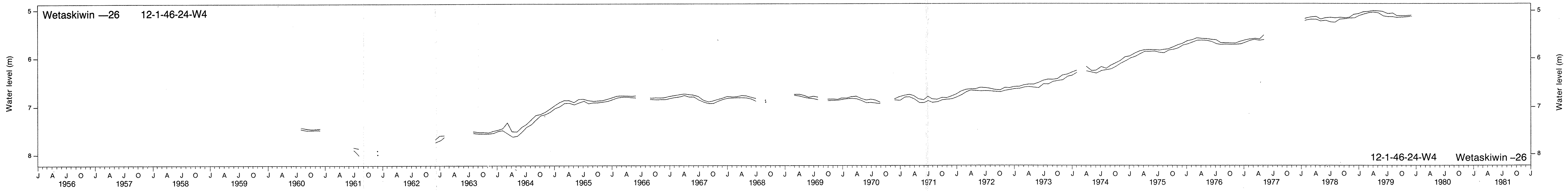

Wainwright Town 6-31-44-6-W4
Water level (m)
20 22 24 26 28
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981

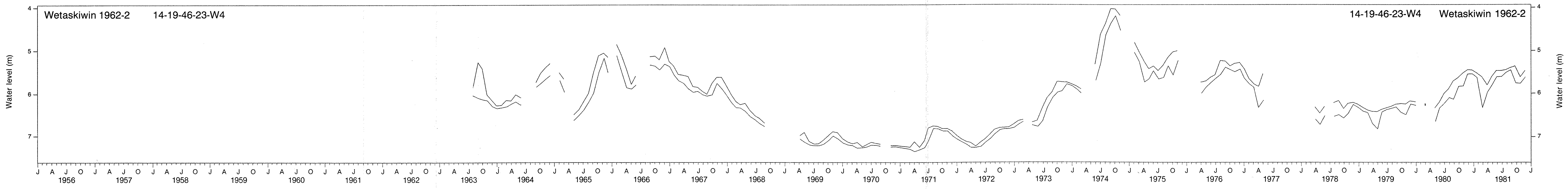

Wainwright Farm 13-20-43-6-W4
Water level (m)
29.6 29.8 30.0 30.2 30.4 30.6
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981


Wainwright Farm —2 13-20-43-6-W4
Water level (m)
14.75 15.00 15.25 15.50
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981


Waterton Dam -1
9-23-4-28-W4
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981


Waterton Dam —5
13-19-4-27-W4
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981


Wetaskiwin —26
12-1-46-24-W4
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981


Wetaskiwin 1962-2
14-19-46-23-W4
Water level (m)
1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981