

United States  
Department of  
Agriculture

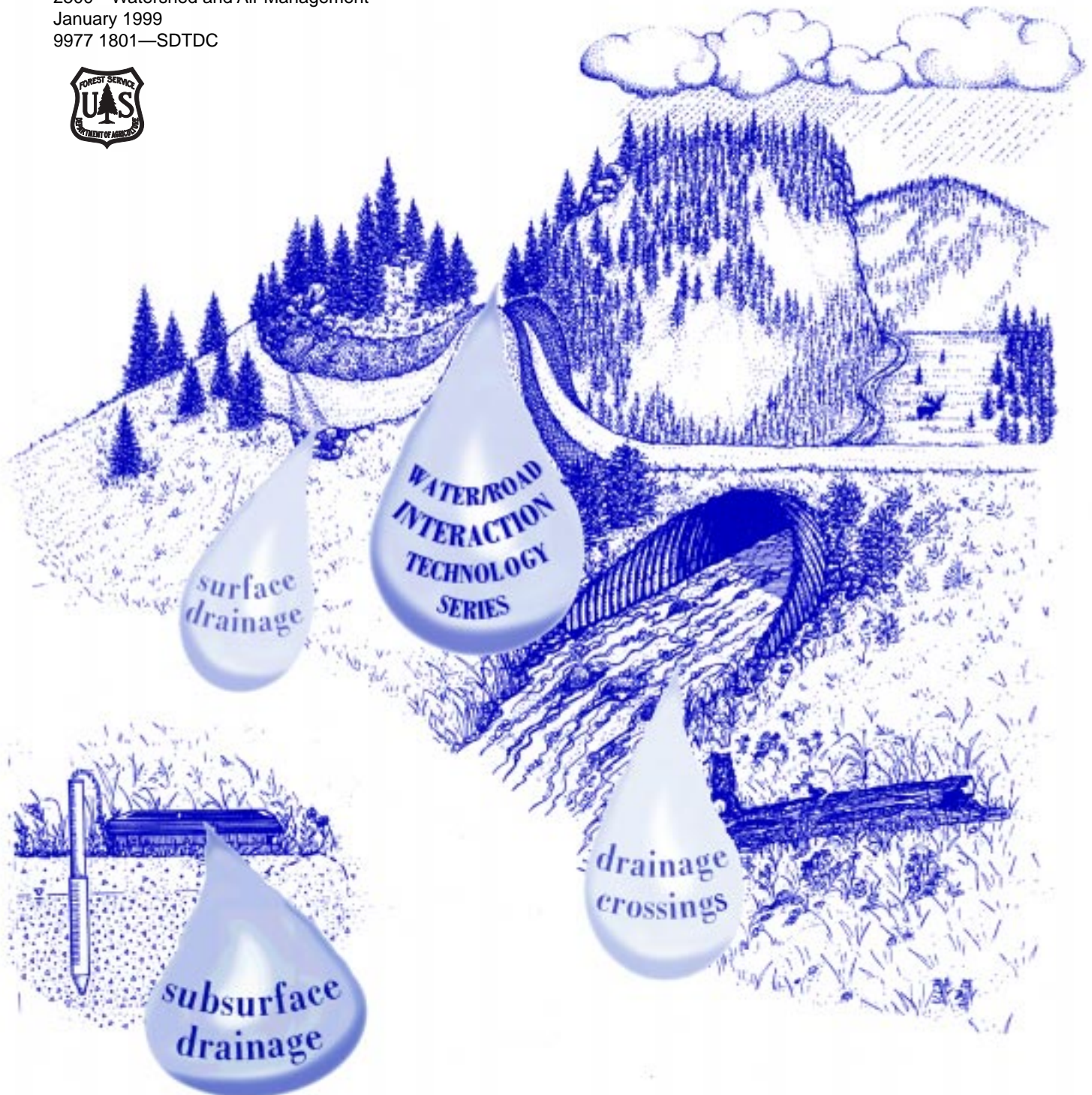
Forest Service

Technology &  
Development  
Program

7700—Transportation Systems  
2500—Watershed and Air Management  
January 1999  
9977 1801—SDTDC



# Measuring Effects of Roads on Groundwater: Five Case Studies





# Measuring Effects of Roads on Groundwater: Five Case Studies

**Keith Kahklen**

*Hydrologist, Juneau Forestry Sciences Laboratory*

**Jeffry Moll, P. E.**

*Senior Project Leader*

*San Dimas Technology and Development Center*

**San Dimas Technology and Development Center  
San Dimas, California**

**January 1999**

---

Information contained in this document has been developed for the guidance of employees of the Forest Service, USDA, its contractors, and cooperating Federal and State agencies. The Department of Agriculture assumes no responsibility for the interpretation or use of this information by other than its own employees. The use of trade, firm, or corporation names is for the information and convenience of the reader. Such use does not constitute an official evaluation, conclusion, recommendation, endorsement, or approval of any product or service to the exclusion of others that may be suitable.

The US Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, gender, religion, age, disability, political beliefs, sexual orientation, and marital or family status. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at 202-720-2600 (voice and TDD).

To file a complaint of discrimination, write USDA, Director, Office of Civil Rights, Room 326-W, Whitten Building, 14th and Independence Avenue, SW, Washington, DC 20250-9410 or call 202-720-5964 (voice or TDD). USDA is an equal opportunity provider and employer.



# CONTENTS

INTRODUCTION .....	1
METHODS .....	1
ROAD AND SITE CONDITIONS AT FIVE CASE STUDY SITES .....	2
RESULTS AND DISCUSSION .....	2
Greens Creek Transects 1 and 2 .....	2
Wrangell Island Transect .....	6
Margaret Lake and Indian Point Transects .....	8
SUMMARY AND CONCLUSIONS .....	12
FURTHER INVESTIGATION REQUIRED .....	13



## INTRODUCTION

This report presents five case study site investigations of road effects on groundwater levels. Levels were measured by both electronic and hand methods in accordance with methods and equipment discussed in the companion document in this series entitled "A Monitoring System for Measuring Effects of Roads on Groundwater: Equipment and Installation." These five case study sites are in southeast Alaska. Additional case study investigations from sites in Montana will be added to an electronic version of this paper accessible on the SDTDC homepage by the summer of 1999.

Road effects on groundwater levels are important considerations in determining the overall impact a transportation system imparts on the hydrologic function of a watershed. A complete understanding of the effects of roads on groundwater is difficult because of the

- Nonuniform interception of groundwater
- Heterogeneity of soils
- Variations of soil density
- Differing prism configurations on a given road segment
- Lack of methodology for tracking all components of a catchment's water budget.

Results presented in this report are examples of an initial determination of road effects on groundwater for each of the five sites. From results such as these, the need for further investigation and analysis can be determined based on specific concerns for a given site.

Information concerning road effects on groundwater is needed for ecological, watershed, fish habitat, and buffer strip analyses and is necessary input for optimizing transportation system development activities from an ecosystem management standpoint. This study was designed to assist Forest Service field units in measuring and assessing effects of roads on groundwater and to provide a foundation for

- Developing the ability to predict effects of road prisms on groundwater

- Developing methods of identifying and treating or mitigating effects
- Accounting for groundwater concerns during transportation system activities including planning, location, design, construction, operations, maintenance, and closure and obliteration.

The road prisms in this study, in the vicinity of the groundwater well transects, appear to affect groundwater levels for distances of between 5 and 10 m on each side of the road prism. The typical effect above the road is either a drawdown in the water level just uphill of the road ditch or a bulge or increase in the elevation in this level. Immediately below the road, the groundwater level is typically lower than far above the road, but recovers to those levels relatively quickly.

## METHODS

The Instrumentation and Monitoring section of "A Monitoring System for Measuring Effects of Roads on Groundwater: Equipment and Installation" (hereafter referred to as the "monitoring paper") provides background on both electronic and hand measurements needed for groundwater level monitoring. Monitoring data in this study consist of hydrostatic groundwater depth measurements. These data were electronically gathered using pressure transducers and stored by a data logger at 5-second intervals, averaged over a half-hour time period, and subsequently averaged over a moving 24-hour period to provide smooth graphs. These levels are then subtracted from the depth to impervious bedrock or glacial till, resulting in depth from ground surface to groundwater surface values. Electronic data collected in this manner were reduced and plotted using spreadsheet software on the personal computer.

In this study, electronic data were supplemented with measurements made by hand taping groundwater heights above the impervious layer. Hand measurements serve two purposes. First, they provide a check of electronic hardware performance and accuracy. Second, when superimposed on cross section plots of the ground surface and the impervious layer taken along the groundwater well transect, they provide a quickly

and easily prepared plot of groundwater levels at a particular point in time. Such plots are also producible from electronic data.

An inexpensive and very useful electronic water level indicator can be purchased and assembled for simple and accurate water level measurement in wells. It consists of an electronic kit, WD-2 Liquid Detector, made by Electronic Rainbow, Inc. The kit is modified so that it does not use the plastic contact sensor board. Instead, a length of clear flat television antenna wire is soldered to the main plastic contact board and is labeled in depth units from the end. This is enclosed in a plastic container with a nine-volt battery for field use. Measurements are taken by connecting the battery and dropping the free end of the wire into the well until the speaker buzzes. The depth to water level from the top of the well is then read.

In some areas the methodology discussed in the monitoring paper needs to be modified in order to successfully install monitoring wells. The installation of 1 1/4-inch polyvinyl chloride (PVC) pipe to the necessary depth in rocky soils may prove difficult or impossible. Once the pilot hole is made with 1/2-inch to 5/8-inch ground rod, galvanized 1/2-inch pipe with the end plugged and small holes drilled 300 to 450 mm from the bottom can be driven without too much resistance. This type of well will not allow use of hydrostatic pressure transducers described in the monitoring paper, but will allow use of a tape or electronic water level device for measuring well water depths.

## **ROAD AND SITE CONDITIONS AT FIVE CASE STUDY SITES**

Groundwater well transects were installed at five sites during the course of this study. A diversity of site characteristics and road building techniques was desired. Road characteristics vary from a simple pitrun overlay on mineral soil (three sites), to a pitrun overlay on muskeg (one site) to a pitrun placed on a cut and fill mineral subgrade (one site). Differing site conditions account for the differing road construction methods. The simple pitrun overlays were placed on a gentle sideslope for gentle road grade conditions, as was the overlay at the muskeg site. The cut and fill subgrade is on

a steep sideslope, which required a steep road grade to satisfy access requirements.

The following discussion of the five case study sites will use two different types of graphs to help interpret the results recorded from field measurements and datalogger records. The two graph types are the transect cross section and the groundwater trace. The required information for the cross section is a survey made along the groundwater well transect to relate the elevations of the ground surface at the wells to each other and the road prism and ditch. Also needed is the depth to the point of refusal or the impervious layer for each well. These depths can be found by measuring the total depth of the well tube after installation and subtracting the amount protruding above the surface.

Hand measurements made during field visits are used to calculate the depth to the water surface in the wells from the ground surface. These are all plotted on a spreadsheet X-Y scatter plot graph. The second plot of the groundwater trace can be accomplished by simply downloading the data from the logger and opening the file in a spreadsheet program. Then a line plot can be made of the water depth in the well, or the depth from the ground surface can be calculated to give a plot similar to the graphs presented in this paper.

Road characteristics for the five groundwater case study sites are displayed in table 1.

## **RESULTS AND DISCUSSION**

Sites in Alaska were desired for this study based on high precipitation levels and associated groundwater response.

### **Greens Creek Transects 1 and 2**

The Greens Creek Mine is located on Admiralty Island in the northern part of southeast Alaska, 10 km west of Juneau. The road on which the study site is located is used for busing mine employees from a ferry landing to the mine ore terminal and main camp on the west side of the island. A different road is used for hauling ore and tailings. The study site receives approximately 2,500 mm/yr of precipitation primarily in the form of rain. Up



Table 1—Road characteristics for five case study sites.

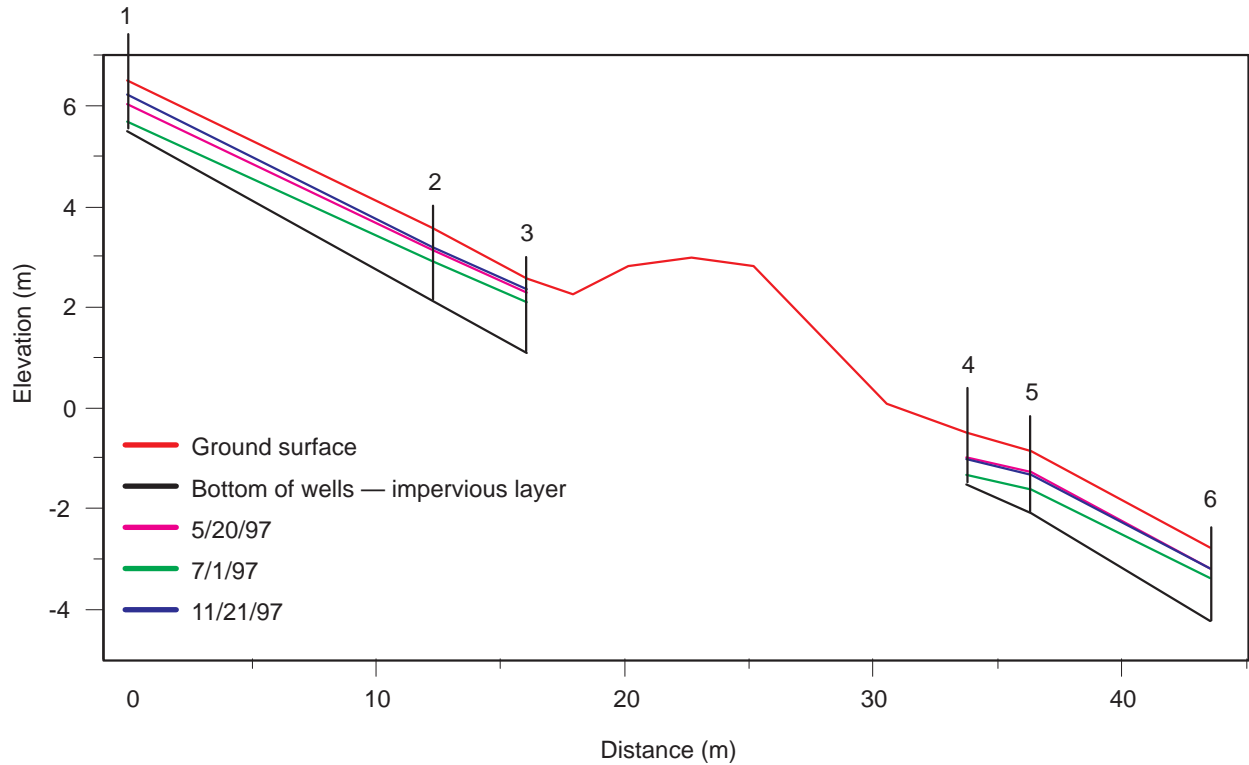
	Greens Creek Transect 1	Greens Creek Transect 2	Wrangell Island Transect	Margaret Lake Transect	Indian Point Transect
Width (m)	5	6	5.6	9 (turnout)	5
Grade (%)	2	2	7	2	14
Back slope length, %	none	none	1.1 m, 50%	0.5 m, 50%	2.8 m, 33%
Fill slope length, %	2 m, 51%	1.7 m, 62%	1.3 m, 78%	1.5 m, 40%	13 m, 45%
Traveled way shape	crown with ditch	crown with ditch	crown with ditch	crown with ditch	crown with ditch
Surface material	pitrun rock	pitrun rock	pitrun rock	pitrun rock	pitrun rock
Construction method	pitrun rock overlay on mineral soil	pitrun rock overlay on mineral soil	pitrun rock overlay on muskeg	pitrun rock overlay on mineral soil	pitrun rock on cut & filled mineral soil
Use	buses, light trucks	buses, light trucks	log trucks, light trucks	log trucks, light trucks	log trucks, light trucks

to 1,000 mm of snow accumulation is common during the winter months; temperatures range from -25 to 27 °C. Vegetation at the site is typical of southeast Alaska with a Western hemlock/Sitka spruce overstory and vacinium and shrub understory. The road and study site are located near the bottom of a glaciated valley with soil depths of 1 to 1.5 m. The soil consists of an organic duff layer and decomposed organics over till, which are all above compact glacial till and bedrock. The transect slope is approximately 21 percent.

Figure 1 displays the groundwater level data gathered by hand measurement for Greens Creek transect 1 and plotted on a cross section of the hillslope. Measured groundwater levels in all wells are consistently lower during the dry period (7/1/97) than during the wet periods (5/20/97 and 11/21/97). Also evident in figure 1 is that the water levels in wells 5 and 6 are at or near the levels shown in wells 1 and 2. During the dry period (7/1/97) the differences are much more

pronounced, with wells 1 and 4 having very low groundwater levels. The other wells have lower water levels, but still exhibit the general trend observed during the wet periods.

The groundwater levels at well 3 are high compared to well 1. Possible explanations for this include a damming effect from the road fill due to soil compaction causing reduced hydraulic conductivity and rerouting of groundwater from the road prism upslope of the site via the ditch. Underground geologic conditions may also be responsible. The level at well 4 is lower than wells 5 and 6, the wells lowest on the slope. These wells appear to have recovered to the levels in wells 1 and 2. One potential reason for the lowering of water in well 4 is rerouting of moisture due to surface concentration and flow caused by the compacted mineral soil of the traveled way. The ditch may be routing water in the form of surface flow away from the site that otherwise—if the road did not exist—would infiltrate the surface and



R9801978

Figure 1—Greens Creek transect 1 cross section at given points in time.

contribute to groundwater levels. A second possibility is that despite the road's age and heavy use, the subgrade is porous and is intercepting the water and routing it away from well 4.

Figure 2 displays a detailed and continuous "groundwater trace" at 30-minute intervals for each well.

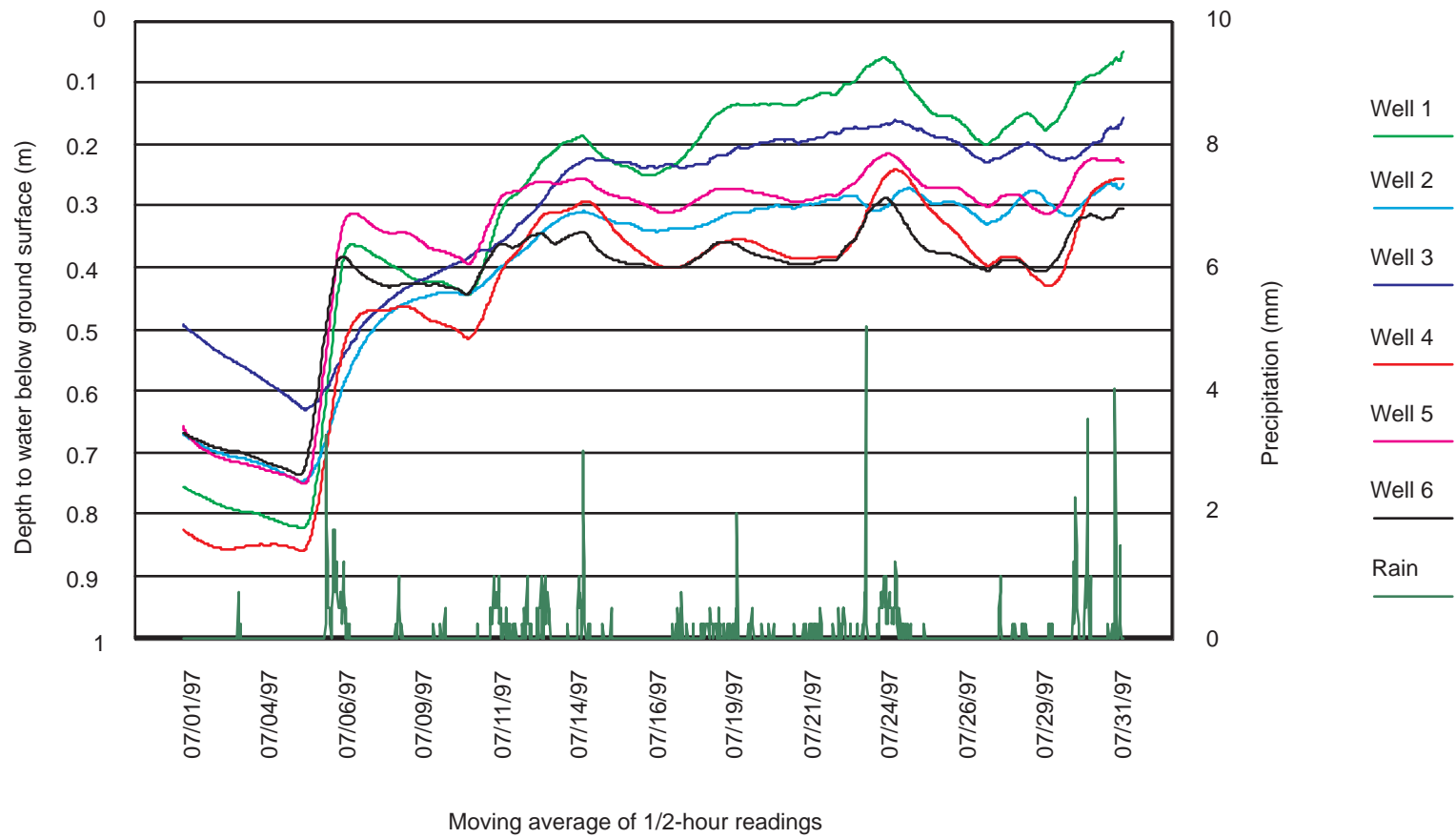
This illustrates groundwater response in each well to both precipitation events and drying periods, allowing a determination to be made of whether the wells are hydraulically connected. A figure 1- type plot can be generated from figure 2 at any point in time. This is accomplished by taking a data "slice" or depth to groundwater in each well at the desired point in time and plotting these depths on the cross section.

Inspection of figure 2 reveals well 4 almost always displays greater distance from ground surface to water level (lower water level) as compared to wells 1 and 2 above the prism. However, care must be taken in directly interpreting results from the plot

in figure 2 due to possible differences in well depths. It may be useful to note the total depth of water measured in the wells from the bottom of the well which represents an impervious layer. This is shown in figure 1 as the distance from the bottom of the well to the groundwater surface. Examining all components of these plots together is the best method for interpreting effects of roads on groundwater hydrology. Results shown in figures 1 and 2 suggest several possible reasons for differences in groundwater levels in the wells above and below the road.

Uncertainties in interpretation arise from the heterogeneous nature of soils, differences in permeability, and disturbance to vegetation and soils during road construction. Wells 1 and 6 are outside the area in which trees were cleared for road construction, possibly affecting localized water levels.

Figure 3, Greens Creek transect 2 cross section, exhibits a large drawdown of groundwater for wet



R9801979

Figure 2—Continuous groundwater trace for Greens Creek transect 1.

and dry periods above the road at well 3 (figures 3 and 4). This is possibly caused by interception of groundwater flow by the ditch or by French drain behavior of the road fill at this site. Wells below the road show a rapid recovery of groundwater levels to those exhibited in wells 1 and 2 above the road. Water was observed flowing out of the toe of the fill on the downhill side of the road. This supports the possibility that the fill is acting as a conduit to drain groundwater near the ditch on the uphill side and discharge it downslope. This water could be recharging the groundwater table below the road.

Figure 4 also indicates that well 3 exhibits uniformly low groundwater levels. Well 3 appears flashier or more responsive to precipitation and dry periods than the other wells. Well 1 seems especially flat and unresponsive. It is possible the well tip was driven into impervious till, a pocket of fines, or a perched water table, all of which might buffer response to changing moisture conditions. Plots for the other wells also seem buffered to varying extents as compared to well 3.

The results at the Greens Creek site from both transects, which are roughly 100 m apart, indicate that there are some interactions between road and groundwater. These interactions appear to be confined to within 5 to 10 m on either side of the road. The effects measured are different for the two transects. One transect indicates the road may be damming the groundwater and rerouting it to surface flow. The second transect appears to indicate an interception of flow and drawdown near the ditch with recharge occurring in the road prism itself. A possible consequence of the rerouting of subsurface flow to surface flow is an increase in erosion and transport capability in the ditch and at the outlet of the culvert. This was not obvious from visual observations during the length of the study.

### Wrangell Island Transect

Wrangell Island is located in central southeast Alaska in the Tongass National Forest. The climate for this area is similar to that of the Greens Creek study site with precipitation and temperatures of about 2,500 mm/yr and -25 to 27 °C. The soils and

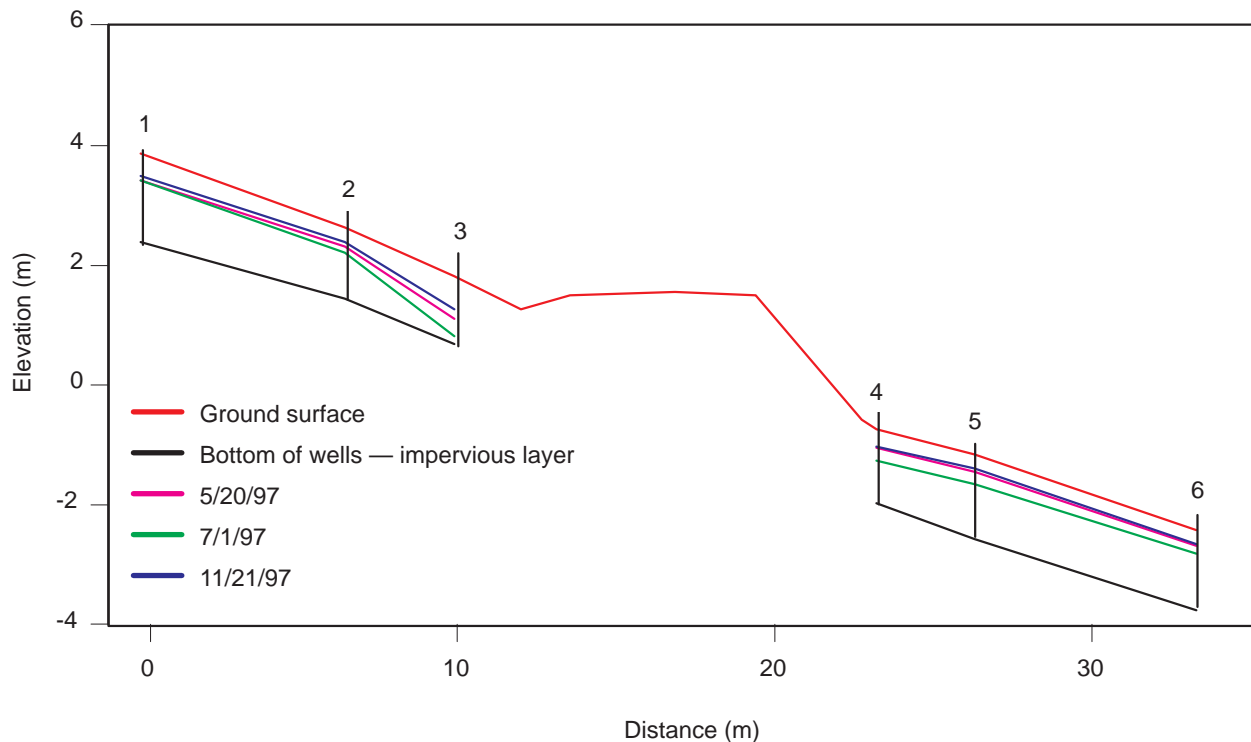
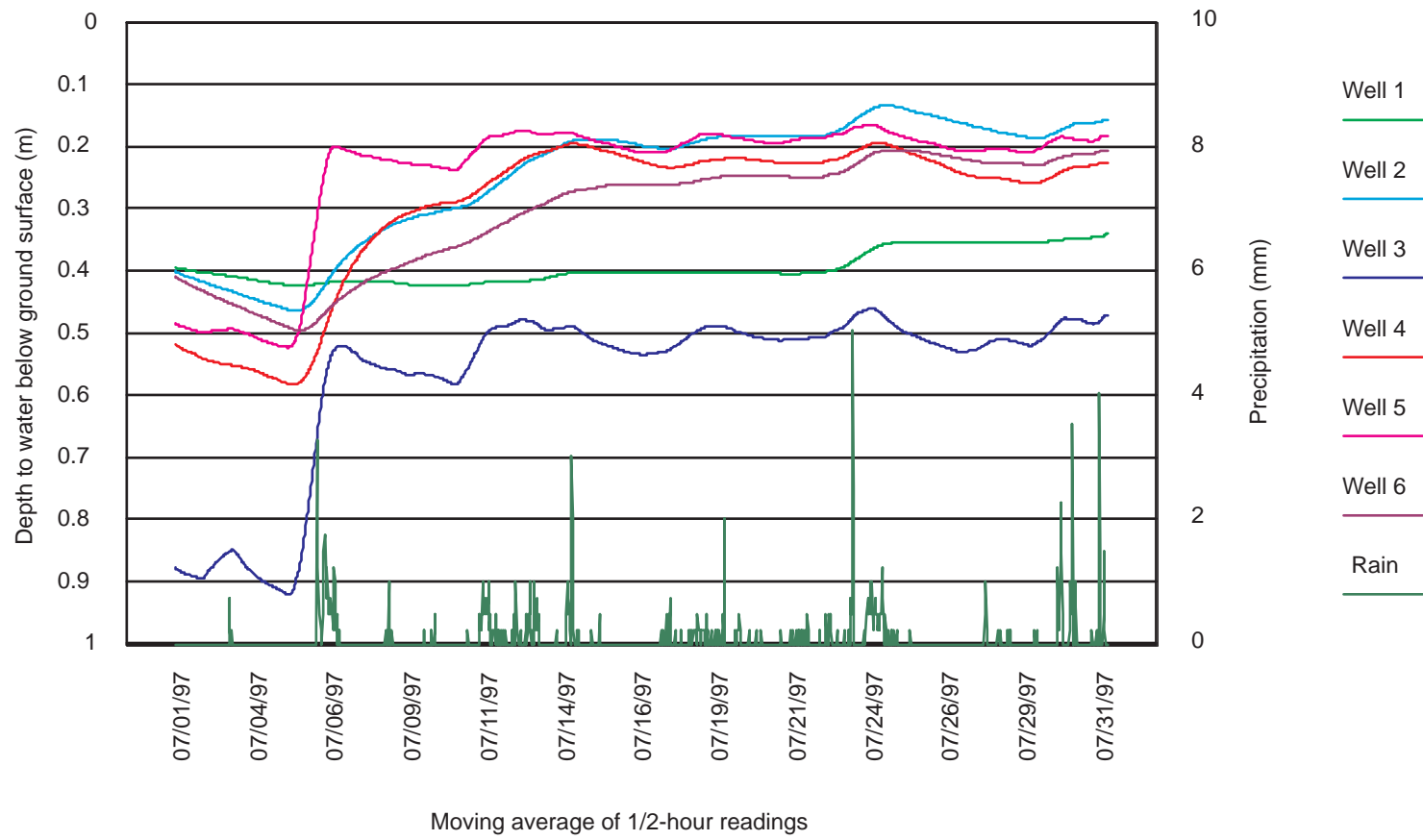


Figure 3—Greens Creek transect 2 cross section at given points in time.

R9801980

z



R9801981

Figure 4—Continuous groundwater trace for Greens Creek transect 2.

vegetation at this site are commonly referred to as “muskeg” in southeast Alaska. These are bog or fen wetlands with poorly drained soils. The soils at this study site consist primarily of peat from 1 to 2 m deep overlaying a thin layer of till over impervious compact till. The road segment crosses a hill near the bottom of a glaciated valley with a hillslope gradient of 13 percent at the transect location.

The transect cross section shows a deep ditch cut into the muskeg subgrade (figure 5). The ditch is over a half meter deep with a back slope over a meter (table 1). Wells 3 and 4 show a drawdown, probably due to the deep ditch, with an apparent quick recovery downhill of the road as evidenced by water levels in wells 5 through 8. The ditch is below the water table, and it is likely interception is occurring along the backslope and ditch cut face. The quick recovery in well 5 suggests that the porous nature of the pitrun material used to construct the road is acting as a conduit for water in the ditch to recharge the groundwater table under and downhill of the road.

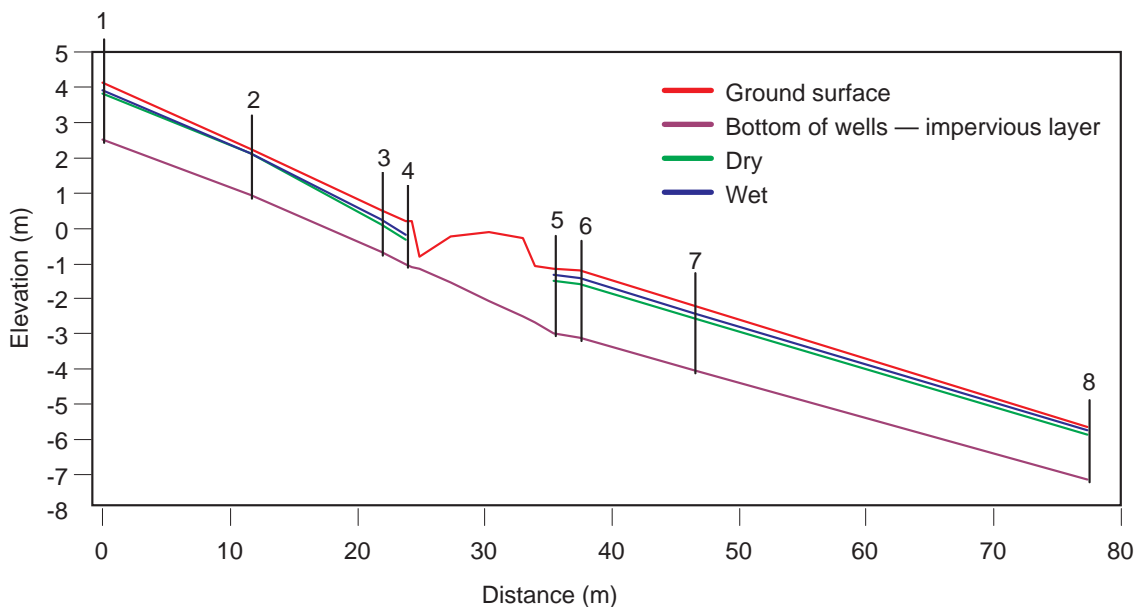
The conclusions drawn from the data in figure 5 are further illustrated in the continuous

groundwater trace (figure 6). The traces for wells 3 and 4 are consistently lower than the other wells substantiating the drawdown effect near the ditch. The fact that all wells react similarly to precipitation events suggests they are hydrologically connected or soil properties are homogeneous at this site. As was evident at the Greens Creek sites, effects of the road on groundwater appear to be localized to within a few meters of the road.

### Margaret Lake and Indian Point Transects

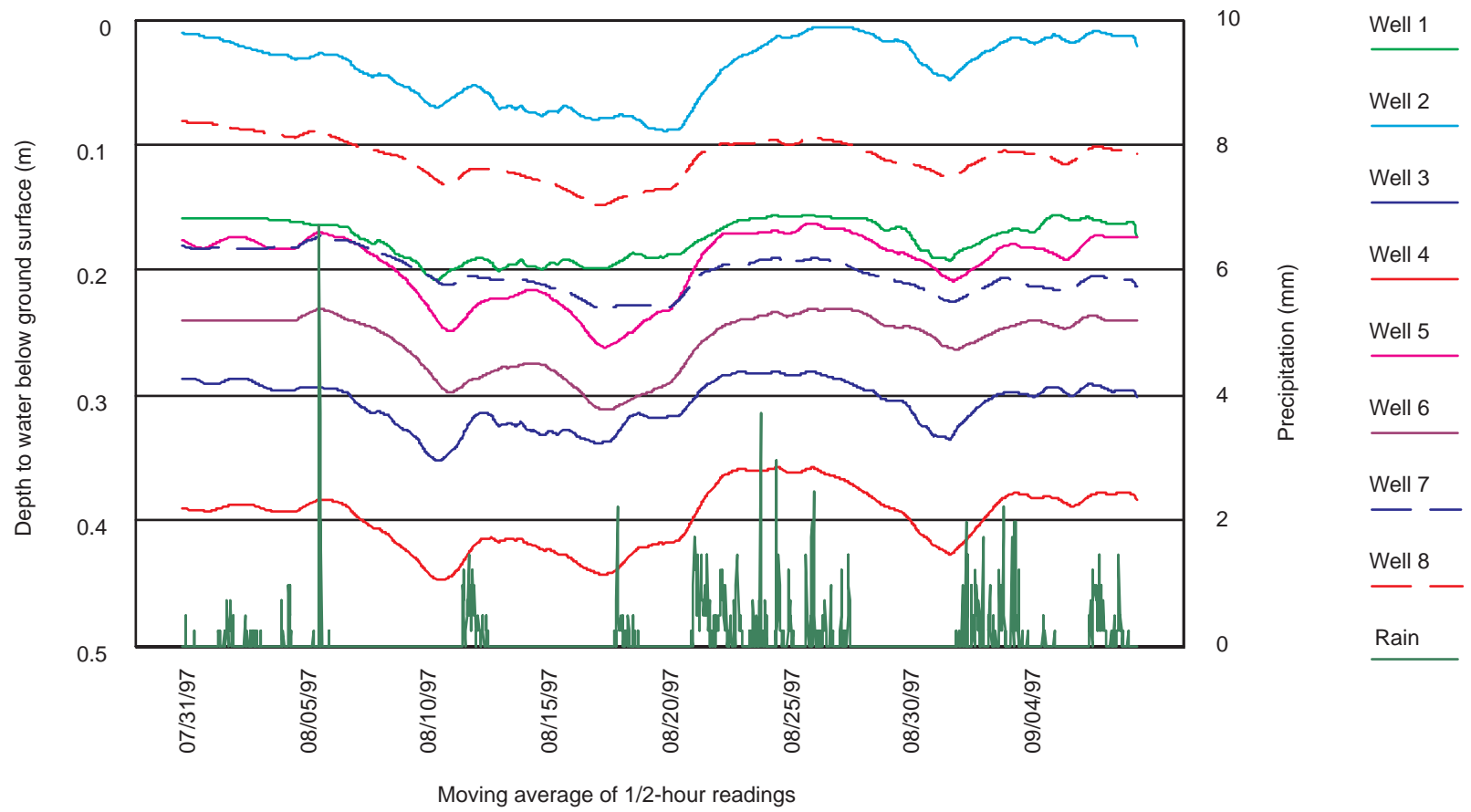
The climate at Margaret Lake on Revillagigedo Island in southern southeast Alaska is somewhat milder and wetter than the previous locations discussed. The precipitation for this area is approximately 3,500 mm/yr and temperatures range from -10 to 30 °C. The soils typically have several periods of freeze-thaw during the winter months. The soils at these two sites are composed of an organic layer over weathered glacial till on top of an impervious layer of compact till for the Margaret Lake road transect and bedrock for the Indian Point road transect.

The vegetation at the Margaret Lake transect is a 30-year-old second growth stand of western



R9801982

Figure 5—Wrangell Island transect cross section at given points in time.



R9801983

Figure 6—Continuous groundwater trace for Wrangell Island site.

hemlock and Sitka spruce with some brush and shrub understory. This road was originally constructed in the early 1960's and has been closed and opened several times. It is located near the bottom of a U-shaped glacial valley and is one of the main haul roads for timber harvest activities.

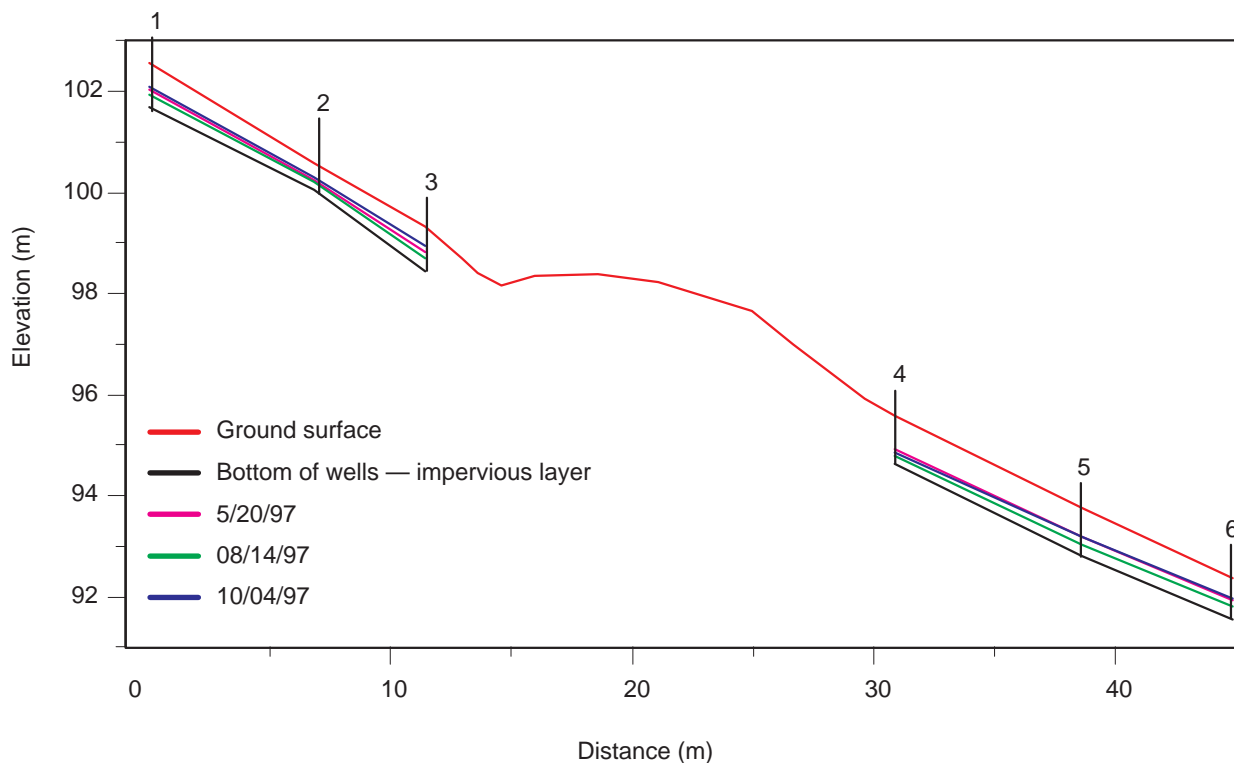
The transect on the Margaret Lake road has similar depths of groundwater for wells 1 and 3 during both wet and dry periods (figure 7). The water levels in well 2 are close to the surface as a result of a shallow impervious layer. As was observed at the two transects at Greens Creek, well 4 just below the road shows a lower groundwater level relative to the surface than observed at any of the other wells. This suggests that the road is intercepting some groundwater flow. As at Greens Creek, water levels are recovering in wells 5 and 6 (figure 7).

The prism appears to have a buffering effect on groundwater fluctuations below the road. This road is approximately 30 years old, making it the oldest

road in this study. The age of the road and the high traffic use may cause a reduction in the porosity of the road prism. Figure 8 shows the groundwater trace recorded for the transect with the wells above the road reacting to precipitation and drying periods much more quickly and at greater magnitude than the wells below the road.

The Margaret Lake road prism at this site has a shallow back slope and ditch; interception of groundwater by the ditch was not observed. However, during very wet conditions, a straight line down from well 3 to 4 on figure 7 intersects the ditch, indicating potential interception.

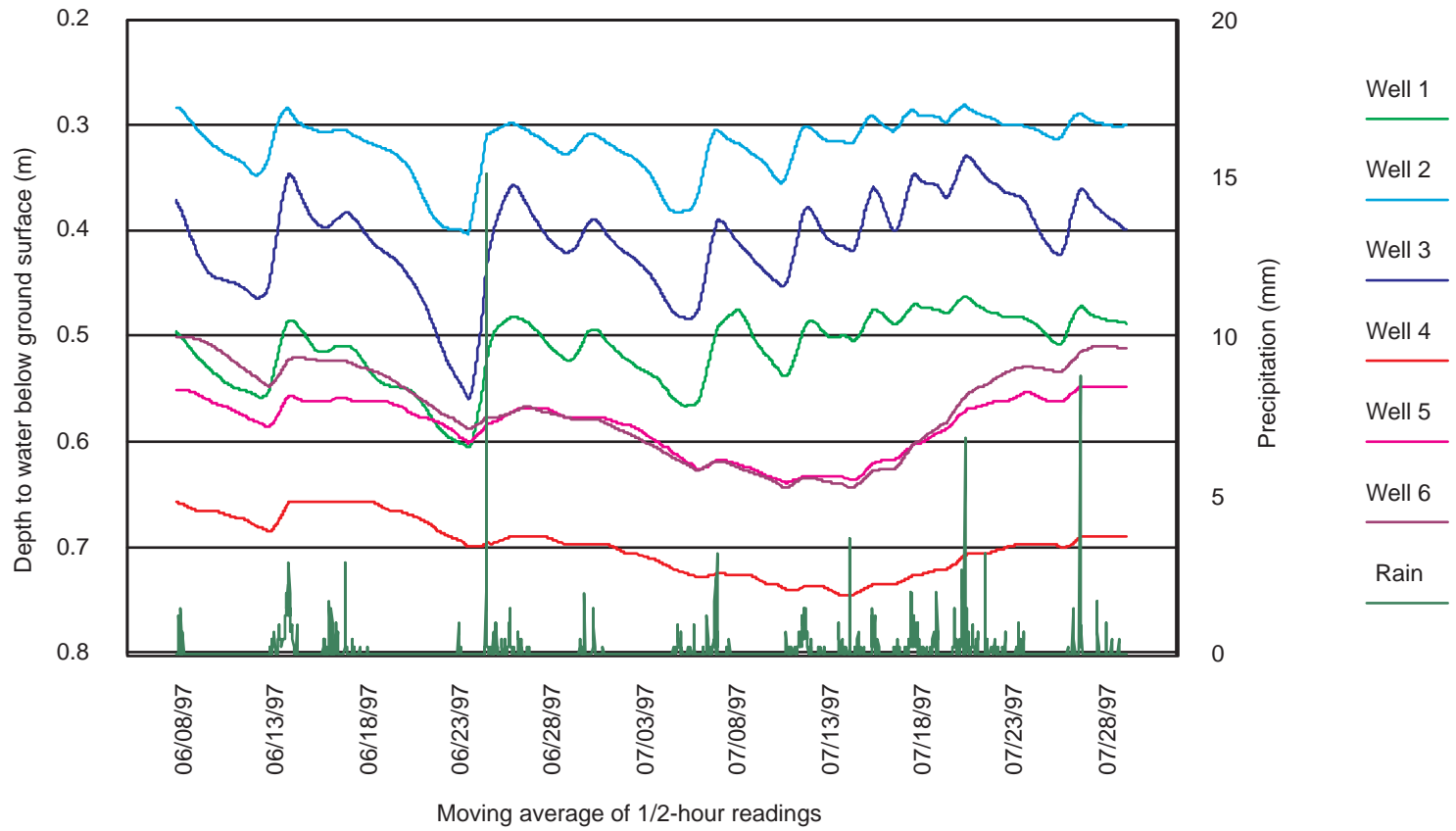
The Indian Point road transect has a 15-year-old second growth stand similar in composition to the Margaret Lake transect. The Indian Point road was constructed in the early to mid 1960's and then reconstructed for timber harvest in 1995. The road is located at midslope in a glaciated valley.



R9801984

Figure 7—Margaret Lake road cross sections at given points in time.





R9801985

Figure 8—Continuous groundwater trace for Margaret Lake road.

This site had only hand measurement of groundwater levels; no electronic measurements were made (see figure 9).

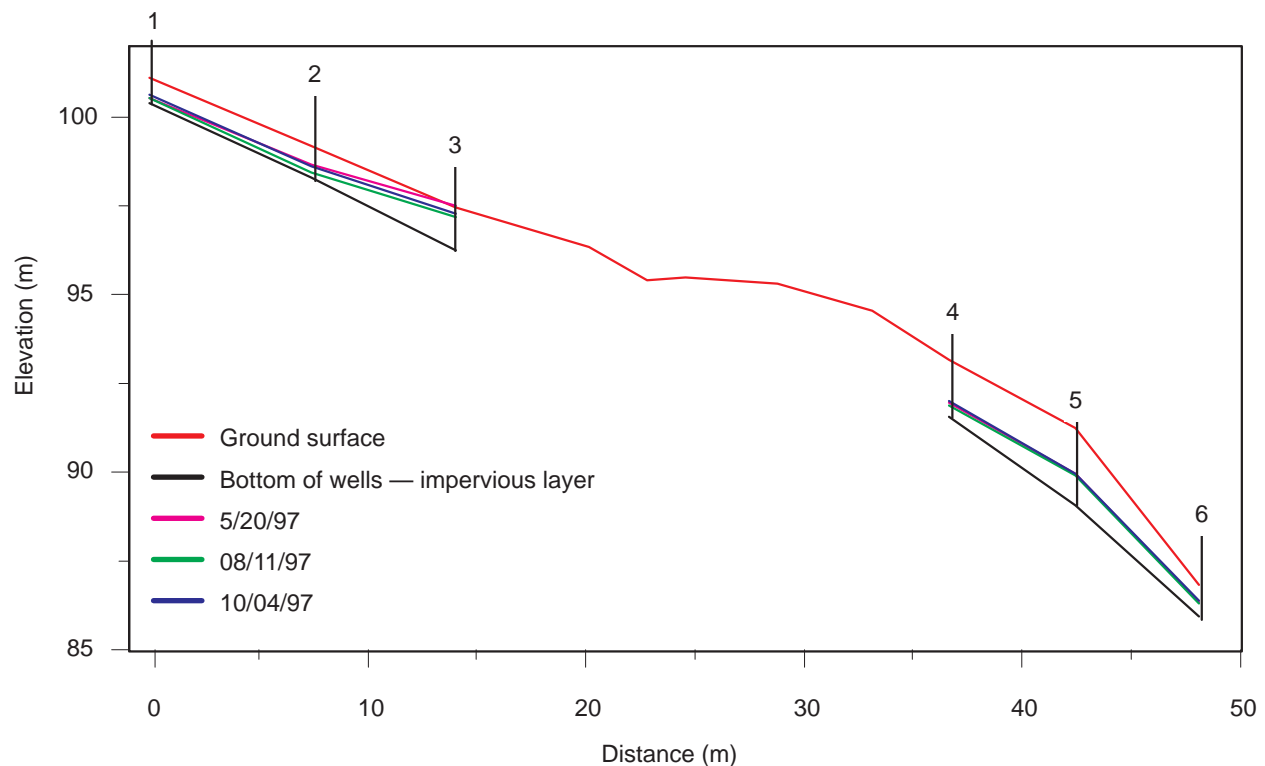
This road was the least desirable site for a groundwater transect of any site in this study. The well transect was not installed perpendicular to the road due to the desire to install the wells in the fall line of the slope. This resulted in a skewed cross section plot depicting an elongated road cross section. Distances between the wells and the road are exaggerated. The road grade is a steep 14 percent, and excess material was sidecast during road construction 30 years earlier, extending the fill slope for several meters (table 1). This may be the cause of a bulge in the groundwater at well 5 (figure 9). The groundwater levels below the road show similar results found at the other sites. The water levels in well 3 are very elevated and near

the surface, which was also observed at transect 1 at Green Creek. This is probably a result of bedrock blocking water flow downslope near well 3 and causing a ponding effect.

## SUMMARY AND CONCLUSIONS

Results from groundwater well transect studies can aid transportation planners and resource specialists in reducing changes to groundwater levels and watershed hydrology due to road prisms.

Groundwater well transects were installed at five sites during the course of this study. These sites represented a diversity of site characteristics and road building techniques. Road characteristics varied from simple pitrun rock overlay on mineral soil (three sites), to pitrun rock overlay on muskeg (one site) to pitrun rock placed on a cut and fill



R9801986

Figure 9—Indian Point road cross sections at given points in time.

mineral soil (one site). Differing site conditions accounted for the differing road construction methods. The simple pitrun overlays were placed on gentle sideslopes and road grades, as was the overlay at the muskeg site. The cut and fill subgrade was built on a steep sideslope with a steep road grade in order to satisfy access requirements.

Results from the five transects described in this study show two effects of roads on groundwater levels on the uphill side of the prism: either a bulge or a drawdown in groundwater level near the ditch. A common result observed at the first well below the road is a depressed water table in relation to the other wells both above and below the road. These effects appear for distances between 5 and 10 m on each side of the prism. Several possible explanations for the observed results are discussed for monitored transects.

## **FURTHER INVESTIGATION REQUIRED**

Further investigation into site specific characteristics is required to support more conclusive statements concerning observed phenomena. For example, a dye test could be used to check the connectivity of the upslope wells to the downslope wells. This test would confirm or reject the assumption that water from upslope wells flows downslope to wells below the road. The dye tracer test could be very useful in determining if water from the upslope wells is intercepted by the ditch or routed through the road prism as has been suggested by observations made at some of the transects. These tests are being used on a related study, and preliminary results appear to be useful.









