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A Monitoring System for Measuring Effects of Roads on Groundwater: Equipment and Installation



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INTRODUCTION

This report presents a system for monitoring groundwater levels used by U.S. Department of Agriculture (USDA) Forest Service field personnel to determine the effects of roads or other management activities on groundwater resources. The report describes effective site conditions, equipment, installation, and methodologies used in this system.

Disruption of groundwater flow by forest roads is perceived as a significant cause of damage to the forest ecosystem. Intercepted, concentrated, redirected, or disrupted groundwater flow by a road prism can lead to increased surface water, accelerated erosion rates, higher peak stream flow, and reduced soil moisture. Varying soil profiles, geology, climates, and road prism characteristics make it difficult to predict the magnitude of groundwater flow disruption. Minimal disruption of groundwater may occur due to a through fill road prism located on highly permeable volcanic material exhibiting deep percolation. In contrast, complete interception of groundwater may occur on a road prism with a 300-mm deep ditch on a slope with 250-mm thick soils overlying an impermeable layer.

A generalization often made concerning effects of roads on groundwater is that a major cause of reduced groundwater flow is attributable to soil compaction associated with road construction and traffic. Compaction would provide only an indirect measure of groundwater flow disruption, and furthermore, no method of predicting deep compaction of forest roads exists. For these reasons, this groundwater study does not attempt to measure the level of soil compaction but directly measures groundwater levels above and below the road prism. Direct measurement is invaluable in assessing the impact of roads on hydrology within a watershed, as opposed to assuming compaction is disrupting groundwater resulting in surface concentration and flow.

The wide variability of natural conditions encountered on National Forest lands require accurate quantitative measurements of groundwater flows be made and analyzed on a

site by site basis. Local measurements can be used to calibrate models with observed conditions so that predictions concerning groundwater flow can be made for other sites based on specific soils, geology, and climate. This quantitative information is needed in:

1. Watershed Analyses, Fish Habitat Analyses, and Ecological Analyses conducted for Pacfish, Stephens Buffer Strip Analysis, and other related studies
2. Evaluating the effectiveness of Best Management Practices (BMP's)
3. Designing road obliteration and construction projects.

Incorporating this level of groundwater flow information into transportation system planning and design could significantly decrease overall impacts of roads on surface and groundwater hydrology. An additional benefit of physically measuring effects of roads on groundwater resources is fulfilling National Forest Management Act requirements on monitoring management activities.

CONDITIONS CONDUCTIVE TO USEFUL GROUNDWATER MONITORING DATA

A first step in locating potential groundwater monitoring sites is to evaluate soils, geology, climate, and topography. Soil and rock characteristics such as hydraulic conductivity, soil thickness, rock fracture, and depth to impermeable layer are important factors when evaluating possible effects of roads and other disturbances. Attempting to measure groundwater levels at sites where deep percolation occurs will not be useful for evaluating activities that disturb only the upper few meters of the soil profile. Meaningful observations should only be expected where groundwater levels are near enough to the ground surface so that road construction, timber harvest, or other management activities could be expected to disrupt the natural flow of groundwater. For situations where the maximum groundwater elevation will remain 1 m or more below the maximum depth of ground disturbance, there will be little or no effect on

groundwater flow. In these cases, monitoring would be ineffective unless unusual conditions such as deep compaction or subsurface topographic ridges exist that could intercept and redirect groundwater flows.

Disturbance due to forest roads, skid trails, and logging are generally limited to the upper 1 or 2 m of the soil mantle. Shallow, inexpensively installed groundwater monitoring wells provide general information except on roads with deep ditches or high cut banks where the depth of impact is a function of the incision into underlying strata. When groundwater elevations are such that deep ditches or large cuts may intercept deeper groundwater flow, measurement would be useful but may require more sophisticated equipment for installation of deeper wells.

Data gathered from groundwater monitoring above and below roads provide information on its interception and redirection into road side ditches. Estimates of increased ditch flow should be incorporated into the design of new roads to ensure adequate control and handling of flow concentrations and increased runoff. After road location, drainage design is the most important facet of low volume road design, and the drainage system is often the most expensive part of a project. Information on groundwater behavior gathered for a broad range of geologic, climatic, vegetative, and slope conditions will provide an invaluable database for predicting behavior under similar conditions. This will make it practical to estimate groundwater response to forest road construction for many sites where impacts and related costs of management activities need to be known.

The magnitude of surface runoff compared to groundwater flow can be used to estimate potential for management activities to alter natural processes. Sites where the quantity of surface runoff due to rainfall excess or snowmelt greatly exceeds the quantity of shallow groundwater flow display little increase in peak runoff discharge when groundwater flow is disrupted. Wetlands and sites with low permeability soils would be an example of this type of condition. In this situation, groundwater

levels would provide little information as to changes in expected peak runoff flows but would be useful for observing down slope groundwater levels and the effects of groundwater levels on down slope ecology and vegetation. Judgment and experience aid in determining where and when groundwater monitoring is necessary.

SITE SELECTION CHARACTERISTICS FOR SHALLOW GROUNDWATER MONITORING WELLS

Shallow groundwater monitoring systems for depths of 1 to 3 m with wells installed manually or with portable equipment are simple, economical, and satisfactory for most situations encountered in National Forests. Such installations provide information on shallow groundwater flows affected by common activities such as road construction and logging.

Key conditions to look for in site selection for groundwater monitoring as indicators of underlying impermeable soils and high water table conditions include surface springs, intercepted flow by road ditches, wet cut slopes, and existence of wetland vegetation. Impermeable till layers and rock can be found by hand probing or soil augers. A general knowledge of the area geology and soils is required to facilitate selection of sites suitable for shallow groundwater studies.

The ideal site for groundwater studies has the following characteristics:

- Road located within the middle third of a hillside
- Road ditches and template typical for area
- Constant hillside slopes above and below the road
- Hillside not dissected by drainages and depressions
- Uniform soil depth up slope and down slope from the road
- Soils 0.5 to 3 m thick overlying impermeable material
- Groundwater table within 3 m of the surface

- Limited presence of rock fragments in soil to facilitate hand installation of wells.

Not all these conditions are achievable in most field situations, and results are increasingly difficult to interpret as deviations from the ideal increase.

TYPICAL GROUNDWATER INSTALLATION

The typical groundwater installation consists of a transect of groundwater wells placed above and below a road along a fall line (figure 1). Three

wells on each side of the road are needed to determine any curvature in the water table. One well should be just above the top of the cut slope (number 3) and one should be just below the toe of the fill (number 4). The other wells should be placed so that drawdown curves above the road and response curves below the road can be detected. The middle well up slope will typically be 5 to 10 m above the top of the fill slope and the upper well an additional 30 m or more up slope. The wells down slope will typically be placed in a similar pattern to those up slope (figure 2).

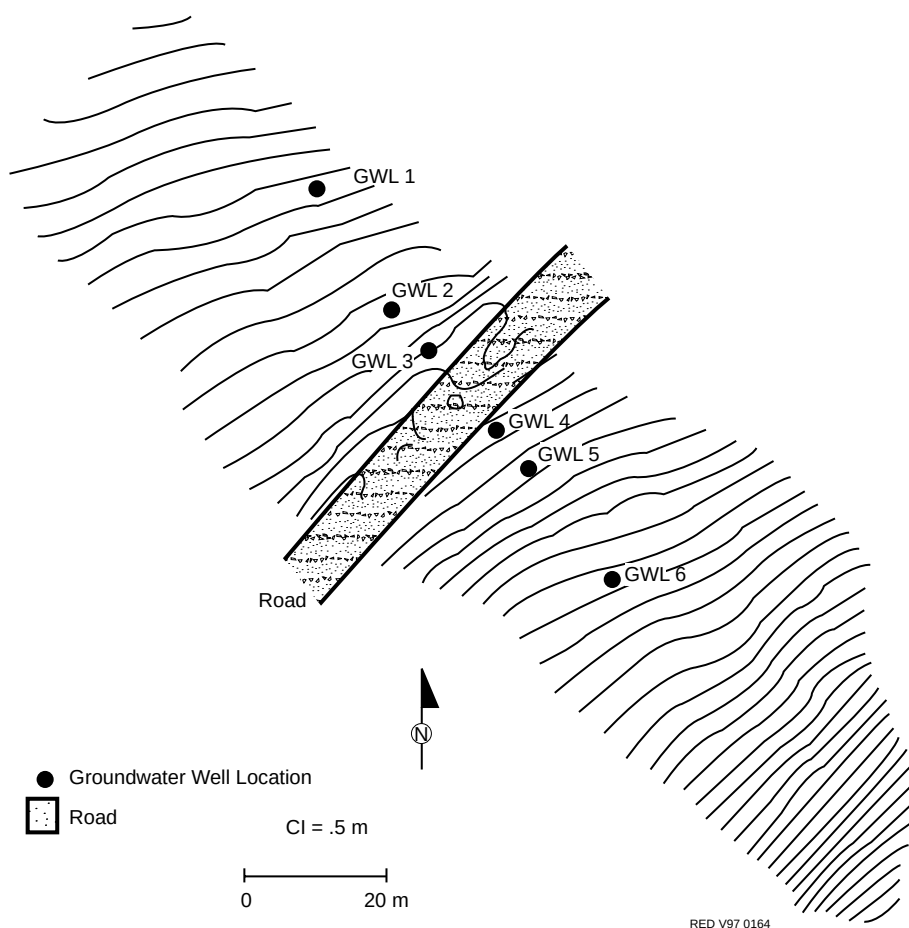


Figure 1—A typical contour map of a groundwater monitoring site.

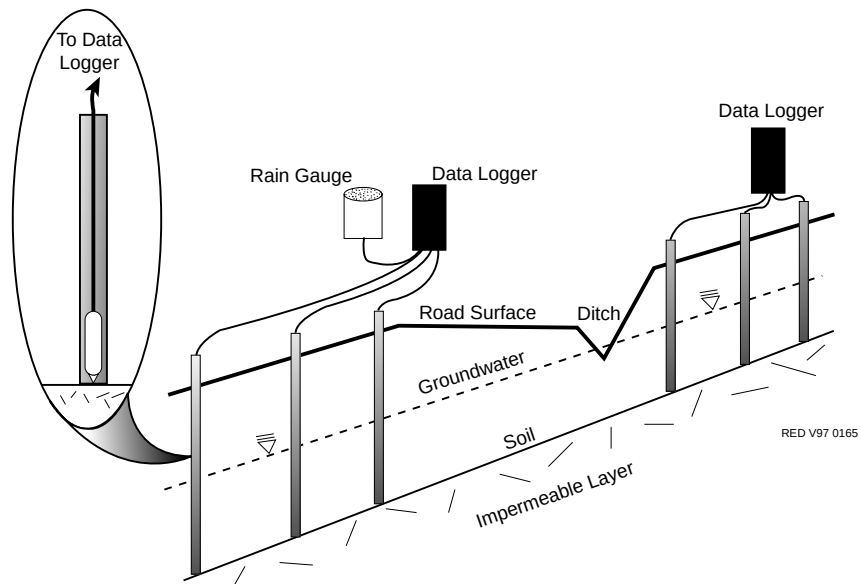


Figure 2—Typical cross section of a road with groundwater monitoring site and instrumentation.

Plots of the depth to the water surface will reveal deviations from a continuous groundwater surface profile. The level of disruption caused by the presence of a road will be indicated by deviations in groundwater levels. Flow net analysis or groundwater models such as the MODFLOW program developed by the United States Geological Survey can be used to estimate the magnitude of groundwater disruption caused by a road or other disturbance.

Polyvinyl chloride (PVC) or steel pipe are suitable materials for well installations. Slotted

PVC well tips with a conical end are available for about \$3.00 each for nominal 1-1/4 in. diameter PVC pipe (figure 3a). Steel well points with screening and tips are available for steel pipe at a cost of \$35.00 to \$70.00 each for nominal 1-1/4 in. diameter pipe. The PVC pipe and tips are considerably less expensive and easier to handle than steel pipe and tips of the same size and should be used wherever possible. Smaller diameter pipe can be used if only hand measurement of groundwater levels will be performed. Pressure transducers generally require the use of nominal 1-1/4 in. diameter pipe.



Figure 3—Equipment used for monitoring the effects of roads on groundwater piezometric surfaces.
 (a) PVC well tip. (b) Unidata Starlogger. (c) Weatherproof enclosure. (d) Field termination strip.
 (e) Hydrostatic pressure transducer. (f) Tipping bucket rain gage.

The 1-1/4 in. diameter PVC wells can be installed by driving a 1-in. diameter steel pipe as a pilot hole to an impermeable layer or to a point below the groundwater table. A heavy duty fence post driver can be used to drive the pilot pipe, and the pipe can be removed by rotating and lifting on two pipe wrenches placed on opposite sides of the pipe. Areas with stones and rock fragments intermixed with soil can be challenging for hand installation. Experience indicates that a smooth soil probe approximately 13 mm in diameter can be used to find a place the probe could penetrate. An electrical grounding rod can be substituted as a probe if necessary because it is smooth, inexpensive, easily replaceable, and suitable for driving. Probing ten or more points can be done rapidly with the small diameter pilot probe until a path

through any obstructions is found. The probe can be removed by twisting on the handle or by using two pairs of locking pliers. The successful probe hole can generally be enlarged using a 1 in. diameter steel pipe that can be followed with a 1-1/4 in. diameter well. Often the type of material can be inferred from the sound and feel of the probe or pipe as it is driven and removed.

INSTRUMENTATION AND MONITORING

Depending on the resources available, various levels of monitoring can be conducted on sites to determine the impact on groundwater due to the construction, maintenance, and use of a forest road. Because the well materials are relatively inexpensive and readily available, the limiting factor on the number of wells at a site will be the

resources and time required for installation and monitoring water depths. A minimum installation for monitoring groundwater above and below a road would consist of at least two wells above and two wells below the road and an accompanying rain gage. A low order site survey is necessary to determine the elevations of the wells relative to the road and each other.

Electronic Readings

Electronic data loggers currently being used on the groundwater monitoring projects are Unidata Starloggers Model 6004 (figure 3b). These data loggers are capable of monitoring eight analog channels and four counter channels. The analog channels are needed for the hydrostatic pressure transducers used to measure water depths in the wells. These analog channels can also monitor other equipment which produce analog signals such as thermistors used for water and air temperature. The counter channels can be used to measure rainfall from a tipping bucket rain gage or any other instrument which sends a signal when a switch closure occurs. The Starlogger 6004 has a capacity to store 128 kB of data. The length of time a logger can run before the memory is filled depends on the number of channels being logged, logging interval, and scan rate. These factors are specified by the operator when the logging scheme is defined using the Starlog Software Program. By entering the Display Scheme Information menu, the operator can get an estimate of the length of time the logger can run before the memory is full. This will show exactly what was programmed for the scheme regarding the instruments, type of log entry, type of reports generated, and the estimated total logging time in days, hours, and minutes. A scheme used on a similar project that logged entries at 30-minute intervals of four wells for 13 months had a total of 92 kB logged and was still operating.

The logger is sealed in a waterproof case with two connector ports for sensor connection and communication. An alkaline battery pack is contained inside the waterproof case, and experience indicates that it will last between 12 and 18 months depending on use. An external

battery can also be used to power the logger and instruments. The logger monitors the battery power internally and will go into a sleep mode if the voltage drops to a preset level. At that point, the data logger will discontinue logging new data to maintain data in memory. Data can be downloaded after the logger is in sleep mode by the routine data downloading method; however, there is a possibility of lost data if the data are not downloaded for a long period of time because the alkaline pack continues to discharge.

A weatherproof enclosure (figure 3c) that contains a mounting frame to hold the logger and a field termination strip is necessary for field installations. The field termination strip (figure 3d) is a circuit board with screw terminals to attach the instruments and external battery power. The strip has a 25-pin plug that fits one of the ports on the data logger and supplies all the instrumentation signals through this interface. There are several options for downloading the data from the logger. The logger can be downloaded while it is still collecting data so that any new data collected after the download time will be appended to the previously collected data. The logger can be downloaded and then reprogrammed with the same scheme to erase the old data and provide more memory space. An advantage of the system is that a logger can be unplugged from the strip and carried to a protected area for downloading without having to disconnect the instruments. Another alternative is to exchange a data logger with a preprogrammed spare.

Hydrostatic Pressure Transducers

The use of hydrostatic pressure transducers associated with data loggers has allowed the collection of groundwater monitoring data at short time intervals for long durations. Water depths can be measured and recorded as average depth, maximum or minimum depth, and instantaneous depth or any combination for the defined time interval. Typically for active monitoring sites, the time intervals have been 30 minutes. The logging interval will be dictated by the physical characteristics of the site,

groundwater response, the frequency in which data will be downloaded, and the intensity and duration of the precipitation.

The Unidata hydrostatic water depth probes (figure 3e) are designed to measure water depth using pressure exerted on a semi-conductor strain gauge element. Pressure measurements are in gage pressure as opposed to absolute pressure by compensating for changes in barometric pressure. To do so, the transducers are constructed with a vent tube encased in the four conductor cable along with the four signal wires. The vent tube equalizes the atmospheric pressure inside the transducer housing. Any changes in the atmospheric pressure on the water surface is also realized through the vent tube. The hydrostatic pressure transducers are rated for a maximum depth, and the accuracy and resolution of the instruments are a function of the total scale. The vent tube on the pressure transducers should be open to the atmosphere and dry; however, achieving both is difficult in moist climates. Wire can be spliced to the transducers to reach wells at the ends of the transects. Fifty meters is the maximum distance a transducer can be located from the logger under ideal conditions, but distance may be further limited by lighter gage wire or lowered battery power.

Tipping Bucket Rain Gage

A tipping bucket rain gage (figure 3f) is an important piece of equipment at a groundwater monitoring site. Observing the reaction of the groundwater to precipitation events is useful in determining conductivity of the soils at the site. Also, once the contributing area is determined, the precipitation record can be used to estimate the expected response in the groundwater well. If flow measurements are taken in a road side ditch, a simple water balance can be calculated to determine the volume of water intercepted by the ditch.

Tipping bucket rain gages are a low maintenance piece of equipment that typically measure rainfall in hundredths of an inch or in millimeters of rainfall. These gages are

precalibrated from the distributor and can be easily recalibrated using several simple methods. Two small buckets are set on a pivot so that the weight of a hundredth of an inch of water over the area of the funnel opening will tilt the bucket down to a position that empties the bucket and sets the other in position to collect the next hundredth of an inch. When the bucket tips, a magnet attached to the center of the two buckets passes a switch mounted in the gage and closes a circuit for an instant sending a signal to the data logger. The data logger is programmed to sum all of these signals to give the total rainfall for a predetermined time interval. The tipping bucket rain gages are reliable and few if any of the instruments should have problems if installed correctly, although they are subject to problems in freezing conditions. Some data have been lost from improper programming of the data loggers; care needs to be taken to ensure this does not happen.

Power Supply

The logger and instruments have several options for a power supply. The data loggers are supplied with a battery pack of six D cell alkaline batteries that can last up to 12 to 18 months. In cold temperatures, the alkaline battery power is reduced and can cause the logger to go into a sleep mode. A deep cycle automotive battery connected to terminals on the field termination strip can supply power to the logging system from this external source and will be less affected by colder weather. When an external power source is supplied, the internal alkaline battery pack serves as a backup to the external power and will supply power if the external power drops too low. A deep cycle automotive battery works well but is subject to theft if not well hidden or located on a closed road.

Manual Readings

Manual readings can be used with the groundwater well transect if funds are not available to purchase electronic equipment. Occasional manual readings should also be taken using a metal tape or electronic water depth measuring device to ensure the data logger and pressure transducers are giving

accurate readings. When using manual reading techniques, a storage rain gage is useful to measure precipitation totals for comparison to hand measurements. Another option for groundwater well measurements is to use ground cork inside the well and a glass rod that is retrievable. The ground cork will stick to the glass rod at the highest water level between site visits. Once the cork line is measured, the glass rod is wiped clean and returned to the well. A water depth measurement during each site visit is useful for checking calibration.

SITE SURVEY

A low order site survey of the well transect and contributing area is necessary to establish a base level for groundwater height measurements when determining possible influences of roads or other management activities. Such a survey, with a laser instrument or an engineers level, compass, and tape, can be used to prepare a

simple topographic map to determine contributing area and to assess influences of micro-relief and slope on groundwater response.

RESULTS AND PLANNED USES FOR THE GROUNDWATER INFORMATION

Experience shows that installing groundwater wells is relatively easy using the hand installation techniques previously described. The initial results of prototype groundwater installations in southeast Alaska have shown that the instrumentation and automated data collection system performs satisfactorily. The electronic instrumentation made it possible to collect precipitation and groundwater levels at regular intervals for extended periods. A graph of the response of the groundwater to the precipitation events is shown in figure 4. This graph can be used to show if a road is intercepting or impeding groundwater flow.

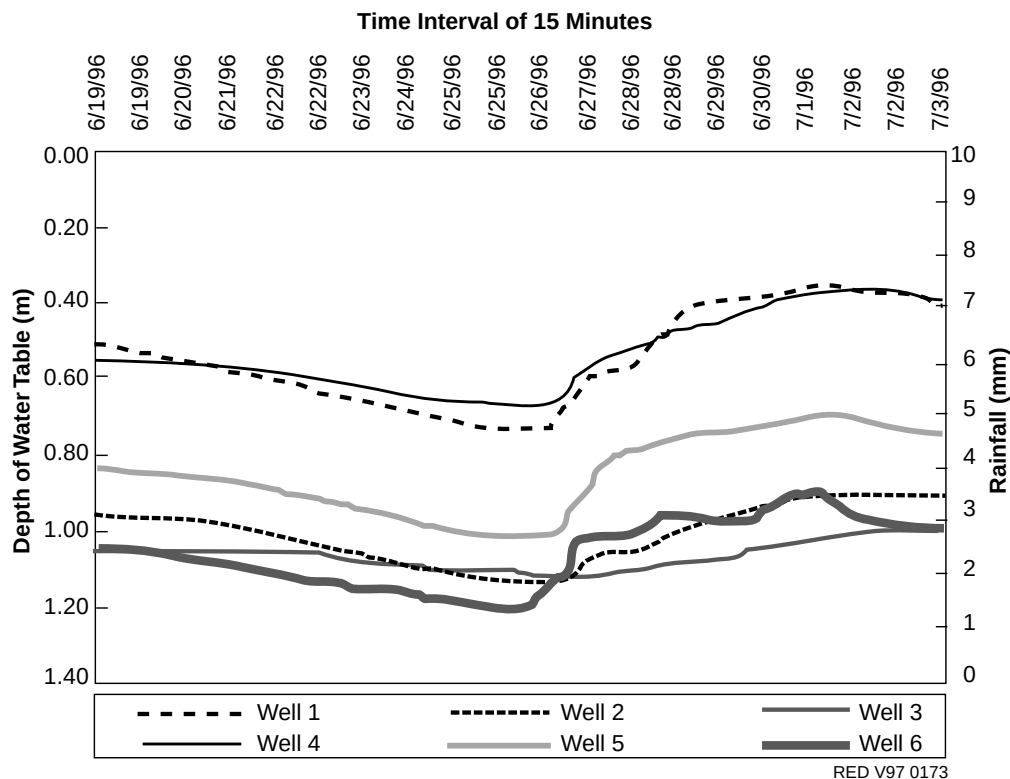


Figure 4—Example of data collected using the electronic equipment.

The data from preliminary groundwater monitoring using this method indicate it will provide useful information for analyzing typical forest roads for groundwater movement. For example, the effects of road construction on soil permeability, groundwater conductance, and concentration of flows in roadside ditches leading to increased cut-bank and ditch erosion can be demonstrated. The monitoring system will also provide numerical data that can be used for weighing the impacts from roads on the flow regime of watersheds, and erosion potential and sediment delivery from ditches and back slopes into adjacent streams. Groundwater flow data associated with roads of varying ages will also provide information that can be used in cumulative effects analyses. An excellent example of a groundwater analysis model that uses data like that being collected is MODFLOW, a program developed by the United States Geological Survey.

The accuracy and quantity of data obtainable using this automated system indicate that it can be used to predict road ditch interception flows required as input to sediment transport and erosion models. An example is the Water Erosion Prediction Program (WEPP) for roads being developed by the Engineering Research Project located at the Forestry Sciences Laboratory on the University of Idaho campus. This additional information establishes a tool for

quantifying flow volumes and the associated energy effects and should reduce the large sums of dollars spent annually on ditch scour and erosion control. Because a major cause of reduced groundwater flow has been attributed to ground compaction associated with road construction and traffic, the question of degree of disruption of groundwater flow due to compaction will be answerable for the wide variety of conditions in the National Forest System.

The results of this methodology have far greater application than simply demonstrating the effects of roads on groundwater. Predicting ditch flows for differing depths of incision into native materials and relating these flows to sediment transport from road surfaces and cuts is an example of how this information should be used. The resulting information will allow more accurate determination of the type of road construction to be used: for example, rock overlay, balanced section, full bench, in slope, or out slope. In addition, data obtained from this methodology inserted into existing groundwater models provide a more accurate tool for predicting flow interception and concentration by roads and better information for slope stability analyses.