Gallatin Valley
Water Resources Evaluation

A Test of the Rationale of Montana Department of Natural Resources & Conservation Proposed Legislation to Amend Montana Water Law

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Executive Summary

The Montana Department of Natural Resources and Conservation (DNRC) is proposing sweeping state-wide legislation which would limit the flexibility of applicants to obtain new beneficial use permits for ground-water appropriations. This legislation pertains to public water supply wells, agricultural wells and exempt wells. DNRC believes “cumulative impacts” are occurring because of ground-water use. DNRC further hypothesizes that this is adversely impacting an unnamed group of senior appropriators.

DNRC has proposed exempt well legislation (HB 104) and augmentation legislation (HB 138) without conducting thorough evaluations of stream flow data or ground-water levels at a watershed or sub-watershed scale. Such analysis is necessary before proposing sweeping legislation that would affect all sectors of Montana. It is important to determine “what the data are showing” before it can be conclusively ascertained if “cumulative impacts” are occurring.

NE&W is currently evaluating the available data at a watershed scale in various areas of Montana to test the validity of DNRC’s “cumulative impacts” hypotheses. This report discusses an evaluation performed for the Gallatin Valley which is located at the northern end of the Gallatin watershed. This valley has one of the highest exempt well densities and number counts of any area in Montana. Hence, if DNRC’s hypothesis is true, then the data should provide statistically definitive evidence that ground-water levels are generally declining and that stream flows are being reduced. Otherwise, the DNRC “cumulative impacts” hypothesis should be rejected.

Climatic, stream flow, ground-water data, and other information were used to test DNRC’s hypothesis.

Based upon the above evaluation, the following were key findings:

1) Stream flow of the Gallatin River and at Logan for a given water year is highly dependent upon each given year’s mountain snow pack in the Gallatin Watershed. Snow pack in the last seven years has been far below average. This has led to a period of lower than average stream flows in the Gallatin River and other streams entering the valley.

2) By far the most significant human-induced influence on stream flow in the valley is surface-water diversions for irrigation.

3) Careful scrutiny of the data from the 1930s to 2000s demonstrated there was no trend for change in stream-flow behavior over this lengthy period of time.

4) There is no evidence of “cumulative impacts” on stream flow from wells.

5) Ground-water use from wells is inconsequential when compared to stream flows. For instance, total domestic (household) consumption of ground-water from exempt wells is negligible and equates to about 0.01 % of Gallatin River flow entering the valley annually. A worst case estimate for consumption from lawn and garden irrigation in the Gallatin County associated with exempt wells equates to about 0.2 % of the water entering the valley annually. <u>For another perspective, the total amount of consumptive use from all exempt wells combined in Gallatin County equates to about 3 to 9 percent of the total ground-water consumption lost to cottonwoods and willows in the Gallatin Valley</u>. A worst case estimate of consumption from other irrigation wells equates to less than 1.7 % of the water entering the valley annually.

6) The actual net effect of wells is much less than the computed percentages provided above because most of these wells are simply used to irrigate land that had been irrigated previously with surface water.

7) There is no evidence that consumptive use has increased in the valley with the growth of city/rural subdivisions and their accompanying use of ground water. <u>In order for consumptive use to increase, there must be an increase in irrigated acreage compared to historically irrigated acreage</u>. Most subdivisions have been placed in areas that had been irrigated historically.

8) The amount of irrigated acreage in Gallatin Valley may have actually decreased with time, especially in areas where rural subdivisions exist. A strong argument can be made that overall consumptive use of water in the valley is declining as a result of subdivision growth.

9) Ground-water levels in Gallatin Valley have not changed significantly since the 1950s.

10) In order to reliably assess the overall implications of ground-water use on stream flows, it is necessary to define the land use both before and after wells are used for irrigation purposes. In a majority of the instances where wells are being used for irrigation purposes that same land had been irrigated before by surface water. Based upon a review of infrared imagery in the valley, it is apparent that there is less irrigation in areas where subdivisions are present. In order accurately quantify the relative significance of wells on the overall water budget in the valley, it is necessary to <u>add and subtract</u> to determine the net changes that may or may not occur.

A detailed hydrologic evaluation of the Gallatin Valley does not support the rationale supplied by DNRC for the legislation defined in bills HB 138 and HB 104. There is simply no underlying data confirming the DNRC Hypothesis of “cumulative impacts” from exempt wells. Nearly all the changes in stream flow that have been observed in the Gallatin Valley over the last decade have nothing to do with exempt wells, or other wells, but are simply due to drought.

Based upon the above analysis, the Hypothesis set forth by DNRC is inaccurate. It also calls into question the need for augmentation and exempt well legislation proposed by DNRC. The findings defined herein are applicable to many of, if not most of, the other alluvial valleys in western Montana. A far more rational approach for determining if control measures are really necessary would be to evaluate watersheds in detail on a regional or sub-regional scale to determine the net significance or lack of significance of wells. That significance should also be defined by completing both the addition and subtraction of water to and from an area before any conclusion is drawn.

Gallatin Valley Water Resources Evaluation

A Test of the Rationale of Montana Department of Natural Resources & Conservation Proposed Legislation to Amend Montana Water Law

Introduction

The Montana Department of Natural Resources and Conservation (DNRC) is proposing sweeping legislation which would limit the flexibility of applicants to obtain new beneficial use permits for ground-water appropriations. This legislation pertains to public water supply wells, agricultural wells and exempt wells. Nicklin Earth & Water, Inc. (NE&W) is currently conducting an assessment of selected watersheds in Montana in order to evaluate the technical assumptions that serve as the underpinnings of DNRC's proposed legislation.

The reasoning offered by DNRC for the proposed legislation is that wells are causing "cumulative impacts" to surface-water flows. DNRC's proposed legislation, HB 104 and HB 138 would have the following effects:

- Virtually all new applications for ground-water appropriation in closed basins in Montana would require an augmentation plan (HB 138); and

- The exempt well conditions would be altered so that following constraints are applicable (HB 104) [for domestic/commercial uses]:

  - The maximum irrigated acreage would be 0.25 acres.
  - The maximum volume of use would be one acre-ft per year.

The evaluations set forth in this report focus primarily on the proposed legislation pertaining to exempt wells. However, an evaluation of the data also provides insights about the relative significance, or lack thereof, of other ground-water uses, e.g., agricultural wells, and public water supply wells.

Overview

According to a Microsoft Power Point presentation by Mr. Tim Hall, DNRC Chief Legal Counsel, dated November 14, 2006 the drilling of exempt wells is a "death by a thousand cuts." This is in reference to DNRC's hypothesized "cumulative impacts." This same Power Point presentation also claims that this "death" is resulting in "known" adverse impacts to unnamed senior appropriators of surface water. These are the same wells serving a variety of entities including private residences, small business/commercial interests, agricultural users and government entities throughout Montana. The DNRC Power Point presentation goes on to state that most exempt wells currently do not irrigate more than 0.25 acres of land anyway. If most do not irrigate more than 0.25 acres, it is unclear what will be accomplished if the proposed legislation offered by HB 104 passes.

The crux of the arguments set forth by DNRC is that exempt wells cause "cumulative" impacts. The primary rationale that DNRC offers in its arguments is set forth in a series of conceptual/cartoon illustrations provided in the Microsoft Power Point presentation (Hall, 2006). The basic premises of DNRC's logic presented in these cartoons are not as clear-cut as DNRC assumes.

A close examination of ground-water level data in the Gallatin Valley does not demonstrate that the growth in number of exempt wells has led to changes in ground-water levels. Stream flow data do not demonstrate that these wells currently cause, or could cause, any significant changes in Gallatin River flows. The claims asserted in the DNRC cartoon illustrations are not supported by the data.

Scientific method dictates that observation data be evaluated before drawing conclusions about how a system will respond to changes. In the case of evaluating the hydrologic response for a system as complex and as dynamic as the Gallatin Valley, it is not just the "well count number" that matters. All substantive factors that influence both ground-water levels and stream-flow observations should be evaluated. For instance, the most significant factor affecting stream flow in the Gallatin Valley begins with precipitation (i.e., snow pack). From a human-induced water consumption perspective, surface-water diversions for agricultural irrigation are by far the most important factor in the Gallatin Valley. Portions of the surface-water diversions are returned to streams, mainly as ground water from irrigation ditch losses. Compared to the surface water diversions, the significance of exempt wells is inconsequential. Reasons for this are set forth based on the data assessment that was performed herein.

Using ground-water level data, there is no evidence that ground-water levels in Gallatin Valley have shown a general decrease in response to exempt well development. Factors that may explain the lack of aquifer-system response in the valley to exempt wells include the following:

- The amount of water being pumped from the ground is relatively inconsequential compared to the overall volume of water that passes through the surface-water network and ground-water aquifers in the valley.

- Another reason is that all variables affecting changes in consumptive use from subdivision activity are not considered in DNRC's "count the wells" approach. DNRC has concluded exempt wells will increase the amount of consumptive use in a given watershed simply on the basis of the number of wells that are drilled and if they are used to irrigate lawns and gardens. For such a conclusion to make sense, it needs to be demonstrated that the use of such wells will also lead to a corresponding and measurable increase in irrigated acreage and that this in turn will lead to increased evapotranspiration. Based upon our review of the data, it is unlikely that land use changes in the Gallatin Valley have led to a net increase in irrigated acreage in the last two decades (main period of rural subdivision growth). Rather, a strong case can be made for just the opposite, especially in areas where the density of exempt wells is higher.

The latter factor can be substantiated using mapping of early 1950s irrigation areas presented in Hackett, et al (1960) and then comparing that mapping to recent infrared imagery obtained by NE&W from files at the Gallatin County Local Water Quality Control District. Using the infrared imagery, it is apparent that the relative percentage of irrigated land has decreased in areas near Bozeman, Belgrade and rural subdivisions. These are also the areas where exempt wells are most prevalent.

Given that consumptive use in the valley is dependent upon the amount of irrigated acreage, it is invalid to conclude that consumptive use increases with the drilling of exempt wells (and public water supply wells, etc.). The opposite conclusion can be reached when all factors are considered. If there is a decrease in overall irrigated area, which appears likely, then consumptive use is probably decreasing rather than increasing. A process of addition and subtraction is relevant here. DNRC has elected to conduct the addition part (wells being added), but it has not done the subtraction (reduced irrigated acreage).

The character of the overall water demands in Gallatin Valley, and in some other portions of Montana are have been in transition over the last one and one-half centuries. Although nearly all the surface-water demand is for agricultural irrigation purposes, some changes in how water is being used and distributed are evolving at a local scale. It is overly simplistic to generally assume that negative "cumulative impacts" from wells will result as postulated by DNRC with these transitions. A "one shoe fits all" approach should not be universally applied to all situations and all different watersheds, especially if the "problem" in most instances is more perception rather than reality. It seems much more pragmatic to apply the scientific method by evaluating the database (e.g., ground-water level data, surface-water data, actual overall water demands, etc.) at watershed or sub-watershed scales to quantify the relative implications one way or another. Solutions, only if needed, could be defined on the basis of these results.

The following shows why caution is warranted in using perceptions as opposed to data for drawing conclusions as to how a complex system has behaved over time. Hackett, et al (1960) discussed the relative significance of ground-water recharge in the Gallatin Valley in association with irrigation activity in the 1950s. This was a time when flood irrigation was the dominant irrigation practice. Some have claimed that the later transition from flood irrigation to sprinkler irrigation (beginning in about the 1970s) led to substantial changes in the magnitude of recharge which in turn affected ground-water levels and also affected the amount and rate that flow returned to the streams. Some of the logical questions to ask to assess the validity of this claim are the following:

- Did this transition yield observation data that confirmed that this change in stress led to observable "cumulative changes" which affected ground-water levels?

- Were stream flows affected?

- Did this cause senior appropriators to be adversely impacted?

The first two of these questions can be answered by simply analyzing the data. For instance, two U.S. Geological Survey (U.S.G.S.) studies provide insights with respect to ground-water levels collected in the 1950s (a period of flood irrigation) to data collected in the 1990s (a period of sprinkler irrigation). These studies are presented respectively in Hackett, et al (1960) and Slagel (1995). The later U.S.G.S. study (Slagel, 1995) concluded the following:

> "Agriculture is the predominant land use in Gallatin Galley. However, population growth has resulted in the establishment of numerous rural subdivisions. <u>Water-level measurements made during this study, coupled with long-term water-level trends, do not indicate any significant water-level changes resulting from increased ground-water withdrawals.</u>"

The combined conversion from flood to sprinkler irrigation, and then the establishment of numerous rural subdivisions with wells (exempt and public water supply), had not led to significant water level changes over this forty-year period of time. Our evaluation of more recent ground-water level data (early 1990s to present) leads us to ascertain that the U.S.G.S.'s conclusion can be extended through 2006.

The second question above can be answered by simply evaluating the stream flow data. For instance, in our evaluations of the surface-water discharge data in the Gallatin River over a period of the record from the 1930s to present, we were unable to determine any observable response in the stream flow records indicative of a transition from flood irrigation to sprinkler irrigation.

In effect, by answering the first two questions, the third is answered as well. The transition from flood to sprinkler irrigation showed no evidence of any significant change in ground-water levels, nor is there any evidence of stream-flow impacts resulting from the transition. Consequently, there is no evidence that senior appropriators were adversely affected by the transition from flood to sprinkler irrigation or by any resulting negligible changes in groundwater levels or stream flow.

The aforementioned example is a case-in-point. Given the response to what some considered a “significant event,” little change in the hydrologic response of ground-water levels and stream flows can be ascertained. It should not be assumed, without examining the data, that use of exempt wells causes the types of “cumulative impacts” and “adverse impacts to senior appropriators” that are claimed by DNRC. DNRC should have evaluated the relevant data in Gallatin Valley and in Montana in general before drawing this conclusion.

There are many factors that lead to ground-water level and stream-flow changes over time. It is paramount that all relevant data are obtained, assessed, and reliably interpreted. Even in areas that have seen the completion of numerous exempt ground-water wells, such as the Gallatin Valley, do the data reveal the “cumulative impacts” that DNRC describes? Where are the valley-wide decreases in ground-water level from these exempt wells? Do stream-flow data show evidence of impacts that can be directly (and uniquely) attributed to the pumping of wells? If trends are being observed in the data, are there other factors, such as drought, that could explain such trends as well?

Finally, even if the cumulative impacts can be detected and quantified on a site specific basis, is should be determined whether existing legislation can address such cumulative impacts via mechanisms such as establishment of ground-water control areas, etc.? Developing legislation specifically to target a perceived problem in one area, and then extrapolating that legislation to other areas, seems to be an irrational approach to addressing water supply management issues in Montana.

The Scientific Approach

A scientific approach should be used to assess hydrologic conditions on a local, watershed, or even regional scale to understand how a system behaves. This is appropriate before posing solutions to a problem that may, or may not exist. Otherwise, the proposed solution may be either inappropriate, unnecessary, or it may create a new set of problems.

One manner of employing the scientific approach is to establish a hypothesis and then test that hypothesis via thorough evaluation of relevant observations. If the hypothesis is demonstrated to be true via the scientific analysis, the hypothesis is accepted, otherwise it is rejected. The scientific method allows individuals with different belief perspectives to approach a given issue (e.g., a perceived problem), to apply data evaluation, and then to ultimately draw the "correct conclusion." For example, the following are alternate hypotheses offering differing viewpoints addressing DNRC's perception of exempt wells causing "cumulative impacts" to stream flows in the Gallatin Valley:

Hypothesis 1: Exempt wells are causing an overall increase in consumptive use in the valley and therefore this leads to changes in ground-water levels and stream flows [required for DNRC's hypothesis of cumulative impacts to be true or accepted].

Hypothesis 2: Exempt wells are not causing an overall increase in consumptive use of water in the valley as changes in ground-water levels and stream flows are not being observed [Antithetical to DNRC's hypothesis of cumulative impacts].

Regardless of which hypothesis the analyst chooses to start with, or the initial bias of the scientist who is undertaking the analysis, a serious and proper evaluation of all the relevant data will allow the analyst to draw the correct conclusion. For example, in order for Hypothesis 1 (DNRC's belief) to be accepted, it must be demonstrated through data evaluation there is clear, compelling and statistically significant evidence that exempt wells are causing changes in both ground-water levels and stream flows. If this can be demonstrated, then Hypothesis 1 is accepted. Otherwise, Hypothesis 1 is rejected.

For Hypothesis 2 to be accepted, the data would have to demonstrate a compelling case that there are no "cumulative impacts." If the data exhibit evidence that demonstrates there are "cumulative impacts," then Hypothesis 2 would be rejected. Ultimately, each analyst, regardless of the initial point of view would have ended up drawing the same conclusion based upon data as the acceptance of Hypothesis 1 is the same as rejection of Hypothesis 2, and vice versa.

DNRC has chosen to define and accept Hypothesis 1 without conducting a thorough analysis of all the data. It is assuming that a simple well count suffices to conclusively determine that "cumulative impacts" have resulted and this in turn has led to adverse impacts to an unnamed group of senior appropriators of surface water. The scientific method requires that all substantive variables affecting the outcome, and the data itself (e.g., ground-water levels, stream flow, climatic factors, water use practices, etc.) be assessed, before drawing conclusions. In other words, the DNRC has failed to analyze what the evidence shows.

Care must be taken to account for as many factors as possible before drawing a conclusion. This includes completing the addition and subtraction discussed earlier. It also includes addressing other natural or human induced factors as well. For example, it is well known that over the last several years stream flows have declined substantially in the Gallatin River (as measured both south of Gallatin Gateway and as measured at Logan). Most scientists attribute such declines to the drought (e.g., reduced snow pack) that has been observed over the last several years. If drought is responsible for ground-water level declines and stream-flow changes, it would be inappropriate to blame something else that is not responsible. For instance, it is evident in reviewing a recent report completed by Ziemer, Kendy, Wilson (2006) that these authors are attempting to defer portions of this drought-related flow reduction in the Gallatin River to housing development in Big Sky, Montana. Rather than conducting an assessment of the data to determine if the "impacts" of Big Sky development could even be measured in Gallatin River flows, Ziemer, Kendy, Wilson (2006) relied on hearsay statements to infer that development was contributing to the lower stream-flow observations. If these authors had conducted a simple quantification of Big Sky water demands and compared those demands to the Gallatin River flows, they would have discovered that any change in flow associated with the Big Sky development is “minuscule” when compared to Gallatin River flows, and that this change simply could not be detected in those observations. Again, why not evaluate the data before drawing conclusions?

Methodology

NE&W conducted a detailed evaluation of the hydrologic database for the Gallatin Valley to determine if the following hypothesis should be accepted or rejected:

DNRC Hypothesis:

> The drilling of exempt wells in Gallatin Valley has led to an overall increase in consumptive use of water [required for DNRC’s hypothesis of cumulative impacts to be accepted for the Gallatin Valley].

If there is any location in Montana that can serve as a test of the validity or lack of the validity of the “cumulative impacts theory” set forth by DNRC, Gallatin Valley is the place. This is because about 11,300 exempt wells have been completed in Gallatin County with most of these present in Gallatin Valley.

The following sources of information were analyzed:

1) Precipitation and snow pack data;
2) Stream-flow data (U.S. Geological Survey data focusing on Gallatin River gaging stations);
3) Ground-water wells and ground-water level data assembled by the Montana Bureau of Mines and Geology (MBMG); and
4) Land use (e.g., evaluation of aerial photographs, subdivision maps, etc.).

In addition, NE&W also relied upon interpretations from the following reports:

1) A Gallatin Valley hydrogeologic study completed by the U.S. Geological Survey (see Hackett, et al, 1960). Interpretations in the report information provide a detailed evaluation of both ground-water and surface-water conditions in the Gallatin Valley representative of the 1950s. It also provides insights of the overall water balance in the valley.

2) The U.S. Geological Survey (Slagel, S.E., 1995) describes a valley watershed study completed to assess ground-water levels and nitrate concentrations in the Gallatin Valley covering 1992-1993. Water level data collected in this report are particularly insightful as they were compared to water level data in the Hackett study.

Later we will extend results from both of the U.S. Geological Survey's studies using results of data collected from approximately 1993 to 2006 by the MBMG. MBMG has forty-one monitoring wells in Gallatin County as part of its state-wide monitoring program. Twenty-nine of these wells are located in the Gallatin Valley.

A companion study was also performed by Dr. Gerald Westesen, Professor Emeritus of Civil Engineering, Montana State University. Dr. Westesen conducted an evaluation of typical consumptive use requirements for a variety of plant cover conditions ranging from native vegetation, agricultural crops, to turf grass, etc. under irrigated and non-irrigated conditions (see Attachment A). The purpose of Dr. Westesen's analysis was to assist in providing a baseline of evapotranspiration rates for the valley. This also served to test the overall water balance computations made for the Gallatin Valley. One goal was to evaluate consumptive use requirements in the valley for three states of land use: 1) Pre-irrigation (natural state); 2) Agricultural irrigation; and 3) Mixed agriculture/urban environment.

Physical Setting

The Hydrologic Cycle

Ground water and surface water are components of a complex dynamic system that is known as the hydrologic cycle. These and other components of this cycle are shown in Figure 1. Precipitation ultimately either seeps into the ground, flows overland and in streams, evaporates, or is transpired to the atmosphere from plants.

Gallatin Valley Physical Setting and Overview

The Gallatin Valley is an intermontane basin contained within the Gallatin River watershed of southwestern Montana (see Figures 1 and 2). An excellent overview of the physical setting is set forth in Hackett, et al (1960). The approximate area of the valley is about 540 square miles. This valley is bounded on the east by the Bridger Mountain Range and on the south by the Gallatin Mountain Range. The predominant land use is agricultural.

Most of the crop land on the valley floor, the Bozeman fan, and the Manhattan terrace is irrigated, as are about one-third of the Camp Creek Hills. According to data compiled by Hackett, et al (1960) from the Montana State Engineer’s office, 107,261 acres (about 168 squares miles) was irrigated in 1952. This represents about 31 % of the land surface area of the valley. Some changes in the overall irrigated area have evolved over time. Based upon infrared mapping, it appears that the overall percentage of irrigated land has declined. This decline is concentrated in areas near subdivisions.

More recently, major economic activity in the valley has become more diversified and includes agriculture, building construction, Montana State University, and evolving technological/entrepreneurial companies. The service industry has expanded as well.

Climate

Much of the Gallatin Valley is semiarid. The average annual precipitation valley wide is 16 inches. Average annual precipitation ranges from 12 inches in the lower northwestern portions of the valley to 26 inches nearer the mountain flanks [see Figure 3 for climate stations and Figure 4].

Temperatures vary substantially with the minimum average daily temperature in the valley being 12 degrees Fahrenheit in January and the average maximum daily temperature in the valley being 81 degrees Fahrenheit in the summer months of July and August (at Montana State University, MSU). The minimum and maximum temperatures ever recorded have been -43° F and 105° F respectively (at MSU).

Geology/Hydrogeology

The Gallatin Valley is considered a high intermontane basin. A detailed and excellent summary of the geology is presented in Hackett, et al (1960). Figure 5 provides recent geologic mapping of the area by Vuke, et al (2002).

The geology bounding the valley is very complex. However, the surface geology within the valley itself is not as complex as surficial deposits tend to consist of either valley floor alluvium, alluvial terrace, alluvial fans or Tertiary strata. The alluvial deposits are the most recent geologic units in the valley. The Tertiary deposits are valley-fill geologic material which consist of moderately indurated to well-indurated tuffaceous sand and siltstone. The Tertiary deposits tend to be finer-grained materials when compared to the alluvial deposits. Both the alluvium and the Tertiary deposits commonly serve as sources of ground-water supply in the Gallatin Valley.

Lower portions of the Quaternary alluvial deposits generally prove to be the most productive aquifers in Gallatin Valley. In particular, Quaternary alluvial strata near the the Gallatin River and E. Gallatin River yield copious amounts of water. Although the Tertiary deposits produce water as well, the magnitude of discharges tends to be lower and less predictable than what is derived from the shallower alluvial deposits. The primary reason for this is, again, related to the fact that the Tertiary deposits tend to be finer-grained. However, intervals of relatively coarser-grained strata exist within the Tertiary and can produce an abundant water supply. For instance, the most productive Tertiary wells tend to be in the Camp Creek Hills area in northwestern portions of the valley. Wells producing between several hundred gallons per minute (gpm) to over 2,000 gpm from the Tertiary have been completed in this area.

The water yielding capacity of aquifers is proportional to a term known as transmissivity. The transmissivities of the Quaternary alluvial valley floor aquifers for the Gallatin River and the E. Gallatin River are typically very high. This explains why these aquifers produce so much water. The Tertiary aquifer transmissivities are typically much lower because of the finer-grained nature of these strata. Nonetheless, the Tertiary aquifer produces sufficient water for stock, domestic, and smaller subdivisions. Again, some portions of this Tertiary aquifer in the Camp Creek Hills area produce enough water for agricultural irrigation wells.

Streams

The two largest streams in the valley are the Gallatin River and the E. Gallatin River (see Figure 3). Stream discharge rates and volume are dependent upon each water year's snow pack. Slightly more than 70 percent of the surface-water flow entering Gallatin Valley enters via the Gallatin River at the mouth of Gallatin Canyon as measured at a gaging station near the Spanish Creek confluence (Hackett, et al, 1960). The remaining surface-water flow enters at other streams along the periphery of the valley.

Data Summary and Evaluation

Snotel Data Collection Network

The Natural Resources Conservation Service (NRCS) installs, operates and maintains an extensive, automated system designed to collect snow pack and related climatic data in the Western United States and Alaska. This system, called SNOTEL (for Snow pack TELemetry), operates over 660 remote sites in mountain snow pack zones. Congress mandated NRCS (then the Soil Conservation Service) in the mid-1930's "to measure snow pack in the mountains of the West and forecast the water supply."

Snow water equivalent is the measure that defines the depth of water that would be produced by a given snow pack. It is measured at a Snotel station by a pressure sensor which quantifies the weight of snow pack that lies on a snow pillow (see Snotel Brochure in Attachment B).

Figure 3 (left portion) shows the local Snotel stations relative to the Gallatin Valley. The three used for the analysis presented in this report are the following:

- Carrot Basin (water years 1967 through 2006)
- Shower Falls (water years 1966 through 2006)
- Lick Creek (water years 1964 through 2006).

Again, the NRCS collects Snotel data for forecasting stream flows. In fact, it is well known that the amount of mountain snow pack (as water equivalent) in each given water year (from October 1 through September 30) dominates the rate that stream flow enters and then exits the Gallatin Valley. The evaluation focused on each of the above three Snotel stations as they possessed a sufficiently long period of record which could be compared to the stream discharge data collected along the Gallatin River.

Other Snotel stations, including those at Sacajawea, Brackett Creek and Lone Mountain, are within the Gallatin River drainage. However, the duration of record at these stations was considered to either be too short or the available record contained too many estimated values. Therefore, the latter Snotel stations were not used in the statistical assessments that are presented in this report.

A summary of the results from the snow pack analysis is given below.

Carrot Basin

Figure 7a provides a summary of the Carrot Basin snow water equivalent over time. The upper plot presents the mean monthly snow water equivalent of the snow pack in inches over the period of record. The snow pack has ranged from less than 20 inches to more than 40 inches over the period of record.

The lower plot in Figure 7a provides a cumulative departure from average snow pack for the period of data collection. Positive (upward) slopes in this plot define long-term periods of above average snow pack whereas negative (downward) slopes express long-term periods of below average snow pack. For example, a period of greater than average snow pack was observed from 1966 to 1976. On the other hand, beginning in about 1999 or 2000, the snow pack has been below average through 2006.

Shower Falls

Figure 7b provides a summary of the Shower Falls snow pack water equivalent over time. The snow pack has ranged from less than 20 inches to more than 40 inches over the period of record.

The behavior of the cumulative departure from average plot (lower plot) in Figure 7b is similar to what was observed at the Carrot Basin Snotel station. A long-term declining trend for snow pack at the Shower Falls station commenced beginning about 1998.

Lick Creek

Figure 7c provides a summary of the Lick Creek Snotel station snow pack, water equivalent over time. Again, the upper plot presents the mean monthly water equivalent of the snow pack in inches. The snow pack has ranged from less than 10 inches to more than 20 inches over the period of record.

A long-term declining trend for snow pack at this station began about 1985 (lower plot of Figure 7c).

Stream-flow Data Evaluation Summary

Long-term stream-flow data have been collected at two stream gaging stations for the Gallatin River as follows (see Figure 3):

- USGS 06043500 (Gallatin River near Gallatin Gateway). This station is located below (north of) the confluence with Spanish Creek. It is also situated up-gradient of valley irrigation ditches. The drainage area above this station is 825 square miles.

- USGS 06052500 (Gallatin River at Logan MT). The station is situated at a location at the northwest corner of the Gallatin Valley. Nearly all water ultimately exiting the valley leaves in the Gallatin River at this location owing to a geologic restriction in this area. The drainage area above this station is 1,795 square miles.

Again, just above 70 percent of the surface water entering the Gallatin Valley is via the Gallatin River as measured at the mouth of the Gallatin Canyon (see Hackett, et al, 1960). The remainder is from other streams entering the valley. Interpretations involving the other streams are given in Hackett et al, 1960.

Figures 8a and 8b provide hydrograph and cumulative departure from average stream flow plots for the Gallatin River gaging stations extending from 1930 to present. Generally, an upward trend in the cumulative departure plot (lower plot) indicates a long term period of above average flow whereas downward trends indicate long term periods of below average flow. Relatively horizontal portions of a given plot demonstrate time periods when the flow is nearer the average flow. The following are general observations that can be made from these plots:

- The cumulative departure plots for both stations demonstrate that the longest period of low flow (drought) was during water years extending from the early 1930s to 1941.

- A long-term period of above average stream flow at Gallatin Gateway and Logan began in the early 1960s and extended to the mid-1970s.

- A more recent long-term period of low stream flow (drought) began about water year 2000.

Given the observations for the 1930s it is noted that the recent drought (since year 2000) is by no means unique for the Gallatin River.

Comparison of Snotel Data to Gallatin River Flows

Again, stream flow in the Gallatin River watershed is highly dependent upon the magnitude of each year's snow pack (snow water equivalent). Figures 9a through 9c present plots demonstrating the relationship between snow pack and stream flow on the basis of cumulative departure from average plots between Snotel data and Gallatin River flows and show almost mirror images of cumulative departure trends.

Figure 10 presents regression plots of the relationship between snow pack and stream-flow observations; and it presents a regression relationship between Gallatin River stream flow as measured at Logan and south of Gallatin Gateway. Again, this figure demonstrates that stream flow entering and exiting the valley is highly dependent upon the snow pack. Figure 10 also demonstrates that the annual mean stream flow at Logan is highly correlated to the annual mean stream flow entering the valley at Gallatin Gateway. This suggests that other surface-water contributions to the valley are directly proportional to those flows entering the valley via the Gallatin River. This is logical as the relative snow pack amounts should vary similarly year to year throughout the Gallatin River watershed. Furthermore, the high correlation of the Logan and Gateway station stream flow demonstrates that the dominant factor affecting flow at Logan is the flow that enters the valley via the streams.

Figures 11a through 11d provide another form of evaluation of changes in a snow pack over time. The upper graph in each of these figures shows the peak month mean water equivalent (PMWE) observed at each Snotel station for a given water year. That figure also plots the average value of the PMWE for the period of record. The lower table in each of the figures tabulates exceedance counts over each given decade. The lower row of each table demonstrates that in the 2000s decade, snow packs have been well below average. For instance, Figure 11a shows that snow packs exceeding 25 inches were observed much more frequently from the 1960s through the 1990s at the Shower Falls station than they have been recently. Beginning year 2000, snow pack exceeding 25 inches at this station has been observed only once in the last seven years.

Figure 11d composites Snotel data for the three stations. The upper plot and the last row of the exceedance table again show that seasonal snow packs in the Gallatin River watershed have declined substantially since the 1990s.

This above Snotel analysis demonstrates what is already well known. The amount of snow pack dominates the magnitude of stream flow entering and exiting the Gallatin Valley. In effect, the relatively lower snow pack of recent years explains the reason that flows in the Gallatin River in the valley have been well below average for these years.

<u>Precipitation in Gallatin Valley</u>

Direct precipitation has been measured at the following climate stations in the Gallatin Valley:

Montana State University (1892 to 2006)

Montana State University Experiment Station (1967 to 2006)

Belgrade Airport (1941 to 2006)

Figures 12a through 12c tabulate both the annual precipitation depths in inches and the cumulative departures from average (mean) for these respective stations.

The plots demonstrate that temporal precipitation patterns vary in the valley from station to station. For instance, both the Experiment Station and Belgrade Airport cumulative departure from average plots indicate relatively lower precipitation has occurred since the 1990s (see Figures 12b and 12c respectively). Yet, this trend is not apparent in the cumulative departure from average plot at Montana State University (Figure 12a).

<u>Comparison of Gallatin River Flows to Valley Precipitation</u>

Annual Gallatin River flows were compared to the annual precipitation data at all three locations located in the valley. The Gallatin River flows demonstrated virtually no correlation to valley precipitation. Figure 13 (upper plot) presents an example showing the relative correlation of Gallatin River flow (Logan) to annual precipitation at Belgrade. That correlation is negligible. The lower plot in Figure 13 compares Gallatin River flow at Logan to snow pack. Again, it is obvious that the mountain snow pack dominates the surface-water flow that exits the Gallatin Valley (Logan).

<u>Overall Water Balance</u>

Figure 14 provides a water balance of the annual volume of water entering the Gallatin Valley for an average water year. The basis of this figure is developed from the information set forth previously. It also adapts information presented in Hackett, et al (1960). Figure 15 provides another valley water balance example under conditions representative of a relatively drier year using 2001 Snotel records, precipitation, and stream flow data.

Referring to Figure 14, the amount of water entering the Gallatin Valley for an average year may be subdivided as follows:

Surface-water Flow	818,000 acre-ft (surface water entering the valley)
Direct Precipitation	465,000 acre-ft

Hence, based upon the aforementioned assumptions, the total estimated inflow into the valley is 1,283,000 acre-ft per year.

The amount of water leaving the valley each year may be subdivided as follows:

Surface-water Flow:	765,000 acre-ft (water leaving the valley at Logan)
Consumptive Use:	518,000 acre-ft

The basis for all the above interpretations are shown in Figure 14 and Figure 15. These amounts do not include the net water entering and exiting the valley as ground-water under-flow. The latter contributions are considered to be small in comparison to the above factors. The actual underflow exiting the valley is probably substantially smaller than that entering the valley.

The water balance figures do not include net changes in storage from ground-water level changes. Those changes are anticipated to be negligible when defined for the period of record (from 1930s to present); and comparatively small when defined on an annual basis.

Nearly all consumptive use in the valley is from evapotranspiration by vegetation (includes both irrigated and non-irrigated land). Consumption from domestic (household) use and water surface evaporation is inconsequential when compared to evapotranspiration. Virtually all domestic water is recycled as treated effluent. According to a Colorado study, household consumptive use (from showers, drinking, etc.) is typically less than 2 % of daily demand (see Attachment C). The Montana Department of Environmental Quality assumes that about 250 gallons per day typifies household demand. Thus, a conservative estimate of the net average consumption per household is 5 gallons per day under full-time occupancy. For the resort area of Big Sky, where a high percentage of homes tend to be occupied only part of the year, the net consumptive use for household use is more likely about 1 to 2 gallons per household per day.

Data obtained from the MBMG Ground-water Information Center (GWIC) site show there are approximately 11,300 domestic wells that have been drilled in Gallatin County. If we conservatively assume that all 11,300 homes with wells consume 5 gallons per day, the total consumption of all homes would be the equivalent of one well pumping at a rate of about 35 to 40 gpm. As a point of comparison, the average flow in the Gallatin River near Gallatin Gateway is about 796 cfs or 357,000 gallons per minute. Hence, the total domestic consumption for all exempt wells in Gallatin County is about 0.01 % of the Gallatin River flow entering the valley. In other words, the total domestic (household use) consumption involving exempt wells in Gallatin County is inconsequential.

Water surface area for ponds in the valley is also small or inconsequential relative to other factors as well.

The most significant sources of water that contribute water directly to evapotranspiration in the valley are in relative order of significance:

Direct Precipitation. Most of the direct precipitation leaves the valley as evapotranspiration. A smaller percentage of the precipitation will percolate through the soil as recharge to the ground water. It is reasonable to assume that about 85 to 90 % of direct precipitation that falls on the valley land surface will be lost to evapotranspiration (Et) in the alluvial valleys of western Montana. The actual percentage will vary in accordance with the field capacity (water holding capacity) of soils at the surface. Another small percentage of the precipitation will evaporate from surfaces. For purposes of the evaluation performed herein, they are combined and referred to as evapotranspiration.

Irrigation. Nearly all the remaining evapotranspiration is from irrigation using surface-water diversions (dominantly by agriculture). Relatively minor portions of the overall consumptive use (compared to surface water) are attributable to wells. A majority of the agricultural irrigation via wells occurs in the Camp Creek area in the western portion of the Gallatin Valley. The remaining well related consumptive use is from public water supply and exempt wells.

Defining the Significance of Exempt Wells on Stream flow

It is well known that there has been a growth in city/rural subdivisions in the Gallatin Valley. Figure 16 provides a plot showing land use in general for the Gallatin Watershed, and the locations of major subdivisions. Figure 17 shows the following:

- Land that had been historically irrigated in the valley (1952);
- Locations of land and rural subdivisions; and
- Locations of wells as defined in NRIS.

It is noted that the density of wells tends to cluster in areas where subdivisions are present. Furthermore, a majority of the wells are placed in areas that had been historically irrigated.

According to DNRC, most exempt well users likely irrigate less than a quarter of an acre of land. This is reasonably consistent with NE&W observations.

Again, there are approximately 11,300 domestic wells that have been drilled in Gallatin County. Not all these wells are located within the Gallatin Valley. It is unknown how many of these exempt wells use ground water for irrigation in the valley. Using DNRC's water rights database, there are approximately 8,000 wells in the main portion of the valley with water rights (including exempt wells).

For purposes of assessing the relative significance of exempt wells county wide, it is assumed that 11,300 exempt wells each irrigate 0.25 acre of land. It should be noted that evapotranspiration for native vegetation occurred prior to irrigation activity. Hence, only the net increase in evapotranspiration associated with irrigation activity should be quantified in order to accurately portray the impact of irrigation on the water budget. This estimate is developed on the basis of the evapotranspiration assessment of Dr. Gerald Westesen, PhD (See Attachment A). The net consumption (exceeding precipitation's normal contribution) associated with that irrigation for lawns is estimated to be 0.95 acre-ft per acre (see Table 1). Under these assumptions, then a reasonable upper limit estimate for the total net increase in consumption resulting from irrigation via exempt wells is approximately 2,700 acre-ft annually. This equates to about 0.2 percent of the total volume of water (1,283,000 acre-ft) that enters the valley annually as either stream flow or precipitation (see Figure 16). It also equates to about 0.4 percent of the surface-water flow leaving the valley at Logan. As another point of comparison, according to the U.S. Geological Survey (Hackett, et al, 1960), evapotranspiration by phreatypes (cottonwoods and willows) in the valley consume from 30,000 acre-ft up to 90,000 acre-ft annually. Hence, the total estimated irrigation related consumption from all Gallatin County's exempt wells equates to about 3 to 9 percent of the total consumption lost to cottonwoods and willows in the Gallatin Valley.

Therefore, under what is considered a worst case (and highly unlikely) scenario for exempt well impacts, the maximum conceivable impact of exempt wells is 0.4 percent of the volume of water leaving the valley annually. From a stream flow perspective, this amount of use cannot be detected as it is far below stream-flow measurement accuracy.

Although DNRC did not undertake any comprehensive analysis for existing data, DNRC's logic stops with the conclusion that exempt wells remove ground water. However, the above analysis is not complete. The impact of changing lands from irrigated agricultural lands to residential lands with exempt wells must also be taken into account. When exempt wells are drilled, in a majority of situations in the valley, the same land had been irrigated historically (see Figure 17). In this case, the land being irrigated by the exempt wells would not have led to any substantive increase in consumption. In fact, based upon the patterns we have observed in Gallatin Valley, it appears that there is a relative decrease in land being irrigated in association with the evolution of subdivisions. Again, a strong argument can be made that development has led to decreases in irrigation water requirements.

To illustrate the latter inference, Figure 18 provides a plot of infrared imagery collected on September 9, 2001. The red portions of the plot indicate vegetation growth. This growth is typically associated with irrigation, or sub-irrigation (see left plot in Figure 18). Careful evaluation of that imagery reveals that in areas where subdivisions are most prevalent (center of Figure 18), and areas where the well densities are the highest (see right plot in Figure 18), red is not as prevalent. This reduced intensity suggests that lands that had been formerly irrigated with surface water are now being irrigated to a much lesser degree with ground water.

Hence, it is unlikely that increased consumptive use has occurred in the valley from increased ground-water development. Rather, it seems more likely that net consumptive use has decreased. This means more water becomes available for use by others when irrigated farmland is taken out of producton and used for domestic purposes.

To summarize, it is necessary to perform all the addition and subtraction before ascertaining just what the consequences are, or are not, when assessing the significance of exempt wells in Gallatin Valley on the overall water budget. DNRC has not performed this analysis.

<u>Defining the Significance of Irrigation Wells</u>

It is also complex quantifying the relative significance of irrigation wells (as opposed to exempt wells) for the following reasons:

- Irrigation wells may be used to supplement surface-water irrigation;
- Irrigation wells may be used to replace surface water; and/or
- Land that had not been irrigated before may be irrigated by wells.

The key, again, is that it is necessary to perform both addition and subtraction before drawing conclusions about the relative significance of irrigation wells.

The addition phase can be performed on the basis of information set forth in the DNRC's water rights database. Based upon that database, about 19,000 acres of land in the valley are now irrigated by ground-water wells (some of this land may have been included in the calculations for the exempt wells that were discussed before). The consumptive use requirement (above effective precipitation contribution) for irrigated land is assumed to be 1.14 acre-ft per acre (assumes 50 % irrigated spring grain and 50 % irrigated alfalfa). This equates to about 22,380 acre-ft annually under a worst case scenario. This represents about 1.7 % of the flow entering the valley annually or 2.9 % leaving the valley annually. For another perspective, this ranges from about 25 % to 75 % of the water that is consumed by willows and cottonwoods in the valley.

<u>Again, we have conducted only the addition part. For the reasons previously defined, it is obvious that subtraction should be performed as well.</u>

This study does not quantify what proportions of the ground-water well irrigation are used for supplemental irrigation, for replacement of surface water, or for new land surface irrigation. Based upon a review of the 1952-1953 irrigation maps set forth by Hackett, et al, much of the area where ground-water well irrigation is currently employed had been previously irrigated with surface water (see Figure 17, right portion). Hence, it is deemed likely that most of the ground water serves either for supplemental irrigation or for surface-water replacement.

There are three alternative possibilities related to the significance of irrigation wells and they are the following: 1) There has been a net increase in consumptive use in the areas where they are present; 2) net consumptive use has not changed; or 3) net consumptive use has decreased.

Hence, without a thorough analysis, it is difficult to conclude if that overall consumptive use has increased, remained the same, or decreased in the valley in association with irrigation wells. Thus, caution is warranted in drawing conclusions that are absolute or in stating that there are "cumulative impacts" from irrigation wells without examining all the factors described heretofore. For instance, what do the ground-water level data and surface-water data show when all factors are considered?

Long-term Ground-water Level Observations

The following sources of ground-water level data exist for the Gallatin Valley:

- U.S. Geological Survey (Hackett, et al 1960) provides water level data from 1952 through 1953;
- U.S, Geological Survey (Slagel, 1995) provides water level data for 1993; and
- Montana Bureau of Mines and Geology (MBMG) provides water level data from about 1993 to present (from state-wide data collection network).

The U.S.G.S. study by Slagel (1995) compared water level data from the 1950s to water level data collected in 1993. This study concluded that no significant changes in water levels occurred over that time interval (1950s to 1993).

Conveniently, in the early 1990s, the MBMG began collecting regular monitoring level data for a 41 well network in Gallatin County. From this network, 29 of these wells are located in Gallatin Valley. Plate 1 presents hydrograph plots of these wells for the valley (see Attachment D for more information about each well). The following are noted in those plots:

- Most of the wells show seasonal variations. Ground-water levels tend to increase during the late spring and early summer when recharge from precipitation and from surface-water irrigation activity is the highest.

- Twenty-six monitoring wells have not shown any significant/persistent trends over time.

- One well GWIC ID 133176[1] showed water levels abruptly declined in about 1999. This response is probably related to ground-water dewatering operations from the nearby TMC/JTL gravel pit operations that occur just to the east of Belgrade.

- One well, GWIC 148531, in the Camp Creek Hills area shows a declining response which is likely related to one or more of the following factors:

  - Agricultural irrigation using ground water;

  - Reduced recharge from drought (e.g., refer to Figure 12b); and

  - Reduced recharge from transition from surface-water irrigation to well irrigation.

- One well, GWIC 97826, shows a declining water level of about 10 feet. This well is located at the southeastern lip of Gallatin Valley.

In summary, although a few localized declines in ground-water level are observed, overall ground-water levels have generally remained stable in the Gallatin Valley. Coupling this information with the conclusion set forth by Slagel (1995), there is no evidence that ground-water levels have changed significantly from the early 1950s to 2006.

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[1] Another GWIC near the JTL/TMC gravel pit, 135735, seems also to have responded to the gravel pit operation the same time as 133176, however, water level change was about 1 or 2 feet vs the approximately 10 foot decline in 133176.

In summary, there is simply no basis to ascertain that exempt wells have caused "cumulative impacts" to ground-water levels in the Gallatin Valley.

Gallatin River Watershed - Outside the Valley

In addition to wells located within the valley, there are 12 more monitoring wells that have been measured in Gallatin County since the early 1990s (see Attachment D). There is no pattern showing long-term trends for decreasing ground-water levels.

Further Evaluation and Discussion

Based upon the data evaluation to this point, NE&W could find no basis to conclude there is any evidence of the so-called "cumulative impacts" that are hypothesized by DNRC. In order to evaluate the data further, NE&W conducted the following procedure:

Step1) Estimated the monthly stream flow entering the Gallatin Valley on an annual basis. This estimate was defined using the stream flow entering the valley via the Gallatin River near Gallatin Gateway. According to valley-wide water study performed by the U.S.G.S. (Hackett, et al, 1960), the total stream flow entering the valley can be approximated by multiplying Gallatin River flow as measured near Gallatin Gateway by a factor of 1.4. Hence, NE&W estimated the total surface-water flow entering the valley to be 1.4 times the flow of the Gallatin River flow near Gallatin Gateway. Figure 19 plots the computed mean monthly flows entering the valley and that flow exiting the Gallatin Valley (at Logan) for the period of record from the 1930s through 2006.

Figure 20 plots the mean monthly flow entering and exiting the valley by decade.

Step 2) The Gallatin River flows at Logan were then subtracted from the computed stream flow entering the valley.

The results of these computations are shown in Figures 21, 22 and 23.

As assessment of the results are discussed below.

Figure 19 can be used to quantify the following factors that affect the surface-water flows entering the valley. For purposes of convenience, the following three periods are defined:

Period 1) Surface-water flows at Logan exceed those surface flows entering the valley (see label a). The difference between these flows represents the relative contribution of ground water during this period of time. The ground-water contributions may be further subdivided to that net flow entering (and exiting) the valley at its periphery as underflow, that surface water returning from irrigation recharge and natural recharge, and that contribution (or loss) due to storage changes. These contributions are also factors at other times of the year as well.

Period 2) Surface-water flow entering the valley exceeds the flow exiting the valley. This represents the period of time when significant amounts of water are being diverted for agricultural irrigation in the valley (see label b).

Period 3) Surface-water flow exiting the valley begins to increase at/near the cessation of the irrigation season (see Label c).

The same procedure was employed as shown in Figure 20. That pattern of behavior is consistent from decade to decade. The relative magnitude of discharge shown in these plots is highly dependent upon the amount of snow pack for each given decade.

Figure 21 present plots showing the difference in stream flow between Logan and that flow entering the valley for different decades. These differences defined in Figure 21 can be affected by the following:

- Changes in ground-water inflow or outflow at the valley boundaries. Such changes are likely to be very small from decade to decade in comparison to surface-water contributions.

- Changes in ground-water storage from decade to decade. Such changes are deemed to be small since ground-water levels have not been observed to change significantly from the 1950s to the present.

- Changes in recharge over a given decade. For example, reduced areal recharge over the valley would likely occur during a decade of drought (e.g., 2000s or 1930s). Increased recharge over the valley would likely be observed during wetter years (e.g., late 1960s and early 1970s).

- Changes in water management leading to changes in consumptive use from decade to decade. For instance, increasing irrigation acreage should lead to increased consumptive use. On the other hand, decreased irrigation should lead to decreased consumptive use.

The point of the above analysis is to examine the difference to determine if there is any evidence of significant “cumulative impacts” to surface flows from changes that evolved from water management. For instance, if there were substantive net increases in consumptive use, then reduced flows at the Gallatin River at Logan should be observed accordingly. If significant impacts occur to cause “cumulative impacts” this should result in a progressive trend for the difference plot (Figure 21) to show “more negative” values during the critical irrigation season (from July through September). For instance, if more water is being lost to consumptive use associated with increased irrigation with time, a long-term trend for “more negative” results should be observed in the plots from July through September (from the 1930s to present).

Figure 22 compares two periods of drought in the Gallatin River, the 1930s to the 2000s. Based upon the upper plot, the stream flow entering the valley was observed to be strikingly similar. The water leaving the valley differed mainly in June with less leaving the valley in the 1930s than in 2000s. This suggests that a relatively higher fraction of surface water was diverted during June of the 1930s decade compared to June of the 2000s.

The lower plot in Figure 22 shows that differences in the flows from July through April of of these decades are strikingly similar. This suggests that the combination of water management factors and other natural factors affecting the flows in the 1930s and 2000s led to nearly identical results. In other words, the net impact in terms of how surface flows are affected by what happened in Gallatin Valley for these two different decades are nearly the same.

Figure 23 compares the 1990s (period of greater precipitation) to the 2000s (a period of drought). Snowpack was higher in the 1990s. The stream flows entering the valley were higher compared to the 2000s. Yet, when flow differences are compared (lower plot), the net impacts of the overall combination of valley factors on stream flow are nearly the same from July through September which, again, is the period of greatest concern to senior appropriators. NE&W conducted similar analysis for all the decades from all the other decades compared to the 2000s. Again, no persistent pattern over time indicative of a trend for "cumulative impacts" to stream flows could be ascertained.

The over-riding conclusion of the above assessment is that the available surface water flow data do not reveal any evidence to support the existence of the "cumulative impacts" that have been hypothesized by DNRC as it relates to the Gallatin Valley. Yet, this valley has one of the highest densities of exempt well development in the State of Montana.

Future Growth Projections/Ground-water Demand

An increasing demand for ground water is likely with future growth in Gallatin County and in other similar areas of Montana. Some may argue that there will be a potential point in time whereby a condition could result that would ultimately lead to "tipping point" that would result in "cumulative impacts." However, before any projections are made the following points should be reiterated:

- Consumptive use via exempt wells is currently very small in comparison to the other primary water budget factors in the Gallatin Valley.

- It is necessary to conduct the addition and subtraction process before determining if there will be a net increase or decrease in evapotranspiration.

Assuming that current growth and ground-water use development patterns in the valley persist as they are currently, NE&W deems it very unlikely that ground water development would increase to the point that it would lead to "cumulative impacts" that would adversely impact senior surface-water users. This is simply due to the fact that irrigated acreage would have to increase in the valley and that is currently not happening. Nonetheless, it is warranted to conduct more detailed planning and analysis to address the future consequences or lack thereof. NE&W believes it is necessary that such analysis be done at the watershed or sub-watershed scale by using the available surface and ground-water data, and by studying previous irrigation patterns, etc. before scientifically supportable predictions can be made.

Additional Comment on DNRC Power Point Presentation

In view of the previous discussions in this report, it is appropriate to comment on two slides presented in the November 14, 2006 DNRC Power Point Presentation which NE&W deems to be misleading and inaccurate. The relevant slides are shown on the left/upper side of Figures 24 and 25. Accompanying those Power Point slides is an evaluation of those slides in light of the analysis NE&W conducted for the Gallatin Valley (beneath and on the right side).

The left side of Figure 24 presents DNRC's conceptualization ostensibly to "educate" the average observer about the relative significance of wells. The gross drawdown projections shown on the left side of Figure 24 do not coincide with what is being observed anywhere in Gallatin Valley. Again, this slide shows only "part of the story" as it does not address the overall water budget factors (adding and subtracting) that accompany land use transitions. The right side of Figure 24 presents a more factually accurate conceptual depiction of what is occurring from the existing exempt wells within the Gallatin Valley based upon the data.

The left side of Figure 25 shows DNRC's postulation of the amount of water consumed with domestic development and lawn and garden irrigation. The following are NE&W's

comments about this slide:

- Evapotranspiration was occurring prior to the existence of irrigation. Hence, the net impact of irrigation is defined on the basis of the increased consumption, not total consumption.

- It is deemed highly unlikely that there is a location anywhere in Montana whereby domestic lawn and garden irrigation consumption equates to 35 inches which is the value that would be required to achieve the numbers presented on the DNRC slide. Presumably, DNRC is implying a water application rate which <u>is not the same</u> as consumptive use. The DNRC slide should be corrected accordingly.

- NE&W has completed an alternative assessment to quantify the consumptive use requirement for domestic lawn and garden irrigation via the information set forth in Attachment A and applying consumptive use estimates presented in Table 1.

Summary and Conclusions

An evaluation of the Gallatin Valley portion of the Gallatin Watershed was conducted by assessing the relevant hydrologic database. Databases evaluated included the following:

- Climatic data (precipitation including Snotel and Local Climate Data)

- Streamflow (focus on long-term streamflow data collected for the Gallatin River)

- Ground-water level data (extending from that collected in the 1950s and 1990s by the U.S. Geological Survey; to Montana Bureau of Mines and Geology data collected in the 1990s to current).

In addition, previous work conducted by the U.S. Geological Survey defined in Hackett, et al (1960) and Slagel (1995), was used extensively.

Based upon that evaluation, the following were key findings:

- There is no evidence of impacts from wells in the Gallatin Valley on Gallatin River stream flow using data from the 1930s through the 2006.

- Stream flow of the Gallatin River at Logan for a given water year depend principally upon each given year's mountain snow pack in the Gallatin watershed. Snow pack as measured by water equivalent in the last seven years has been below average. This had led to a period of lower than average stream flows in the Gallatin River and in other streams entering the valley.

- By far the most significant influence on stream flow in the valley is related to surface-water diversions for irrigation. Well water use is presently inconsequential when compared to stream flow diversions.

- Ground-water levels for most portions of the Gallatin Valley have not changed significantly since the 1950s. Three localized exceptions exist. One of these local area declines is associated with sand and gravel pit de-watering (TMC/JTL sand and gravel pits near Belgrade). Another area is located at the southeastern edge or southeastern lip of the Gallatin Valley. The other area is in the vicinity of Camp Creek Hills in western portions of Gallatin Valley.

- There is no evidence that consumptive use has increased in the valley with the growth of city/rural subdivisions and with their accompanying use of ground water. In order for consumptive use to increase, there must be an increase in irrigated acreage compared to historically irrigated acreage. Most subdivisions have been placed in areas that had been irrigated historically. It appears that irrigated acreage in Gallatin Valley may have actually decreased with time, especially in areas where rural subdivisions exist.[2]

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[2] Another factor not considered in this analysis is the fact that impermeable surfaces eliminate evapotranspiration where they are present. Such surfaces also increase runoff which may ultimately recharge the ground water or leave as surface-water runoff.

- It is likely that overall consumptive use of water in the valley is declining as a result of subdivision growth.

- In order to reliably assess the overall implications of ground-water use on stream flows, it is necessary to define the land use both before and after wells are used for irrigation purposes. In effect, it is necessary to add and subtract prior to assessing the potential for "cumulative impacts" to arise.

In summary, our findings in the detailed hydrologic evaluation of the Gallatin Valley do not comport with the underlying rationale defined by DNRC for the legislation defined in bills HB 138 and HB 104. There is simply no underlying data that confirm that the DNRC Hypothesis of "cumulative impacts" from exempt wells is accurate. Nearly all the changes in stream flow that have been observed in the Gallatin Valley over the last decade have nothing to do with exempt wells, or other wells, but are simply due to drought.

Hence, the Hypothesis set forth by DNRC is inaccurate.

This calls into question the need for augmentation and exempt well legislation proposed by DNRC. NE&W believes the findings defined herein are applicable to many of, if not most of, the other alluvial valleys in western Montana.

NE&W proposes that a far more rational approach for determining if control measures are really necessary would be to evaluate watersheds on a regional or sub-regional scale to determine the net significance or lack of significance of wells. That significance should also be defined by completing both the addition and subtraction of water to and from an area before any conclusion is drawn.

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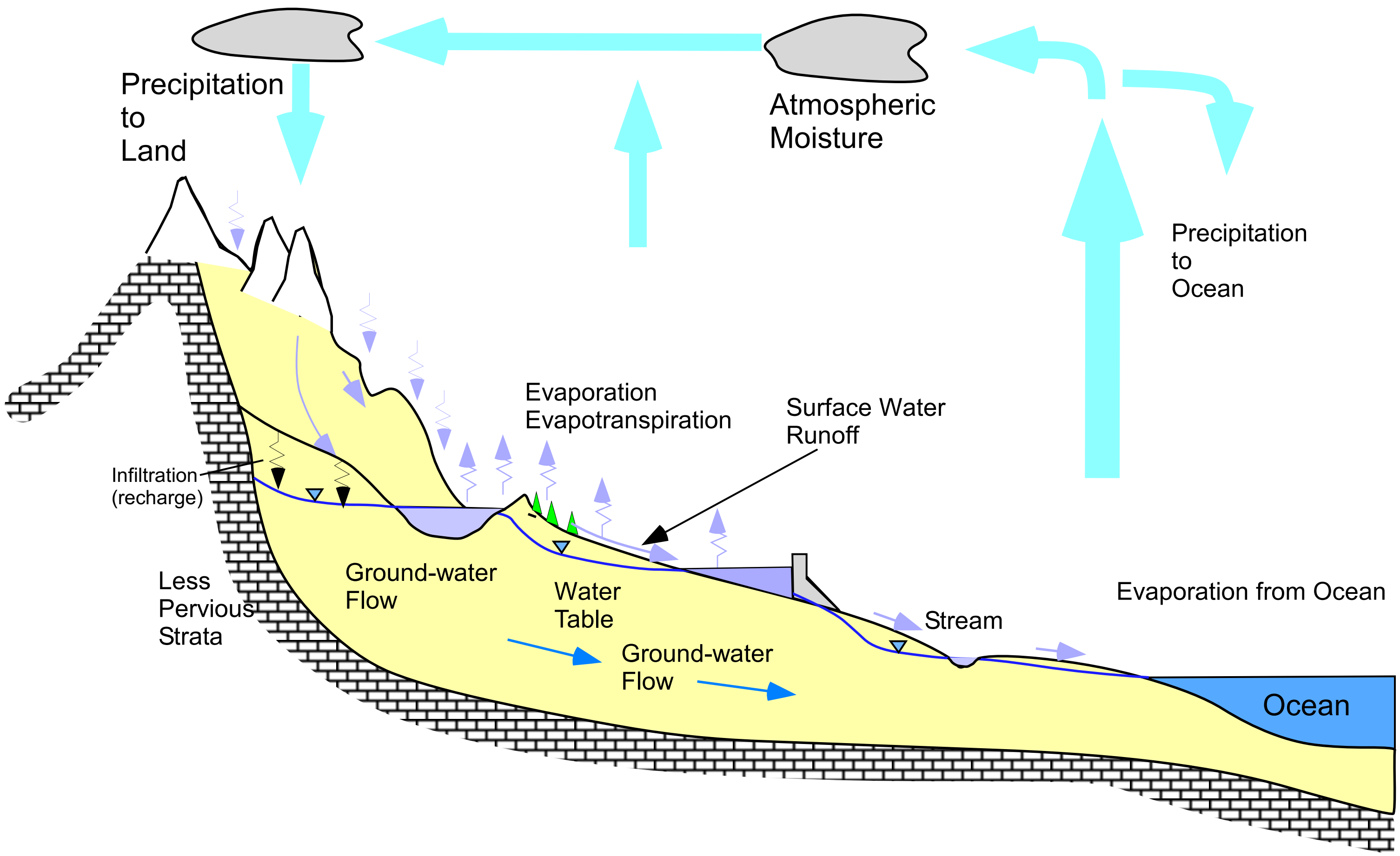
Table 1

Crops and Turf - Gallatin Valley
Based upon Belgrade Climate Conditions

Type Cover	ET Value inches	Effective Precipitation, in	Irrigation Portion In	ac-ft/acre
Agricultural Crops				
Irrigated Alfalfa (average of Bozeman, Belgrade)	22.45	5.54	16.91	1.41
Irrigated Spring Grain (average of Bozeman, Belgrade)	16.90	5.54	11.36	0.95
50 % of Each Crop	19.68	5.54	14.14	1.18
Development				
Irrigated Turf or Pasture Grass *	20.28	5.54	14.74	1.23

Note: both effective precipitation and ET values are based upon the average of Bozeman and Belgrade values. See Attachment A for further details.

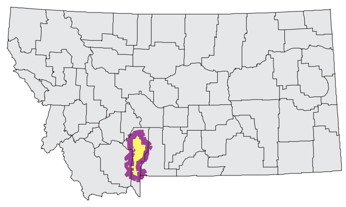
* A relatively higher effective precipitation of 8.85 inches (average of 10.6 for MSU and 7.1 for Belgrade) for turf could have been employed. The use of 5.54 inches is deemed to be very conservative for estimating consumptive use for turf.



Date: 1/5/07 c:\leg\gal\rep\fig_01 For Doney Law Firm	NICKLIN EARTH & WATER, INC.	**Global Hydrologic Cycle**	**Figure 1**

GALLATIN
Watershed

Slope Classes from NED



0 5 10 15

Mapscale 1: 488000 Scale in miles:

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Montana State Library — 1515 East 6th Avenue
Helena, Montana — (406) 444-5357

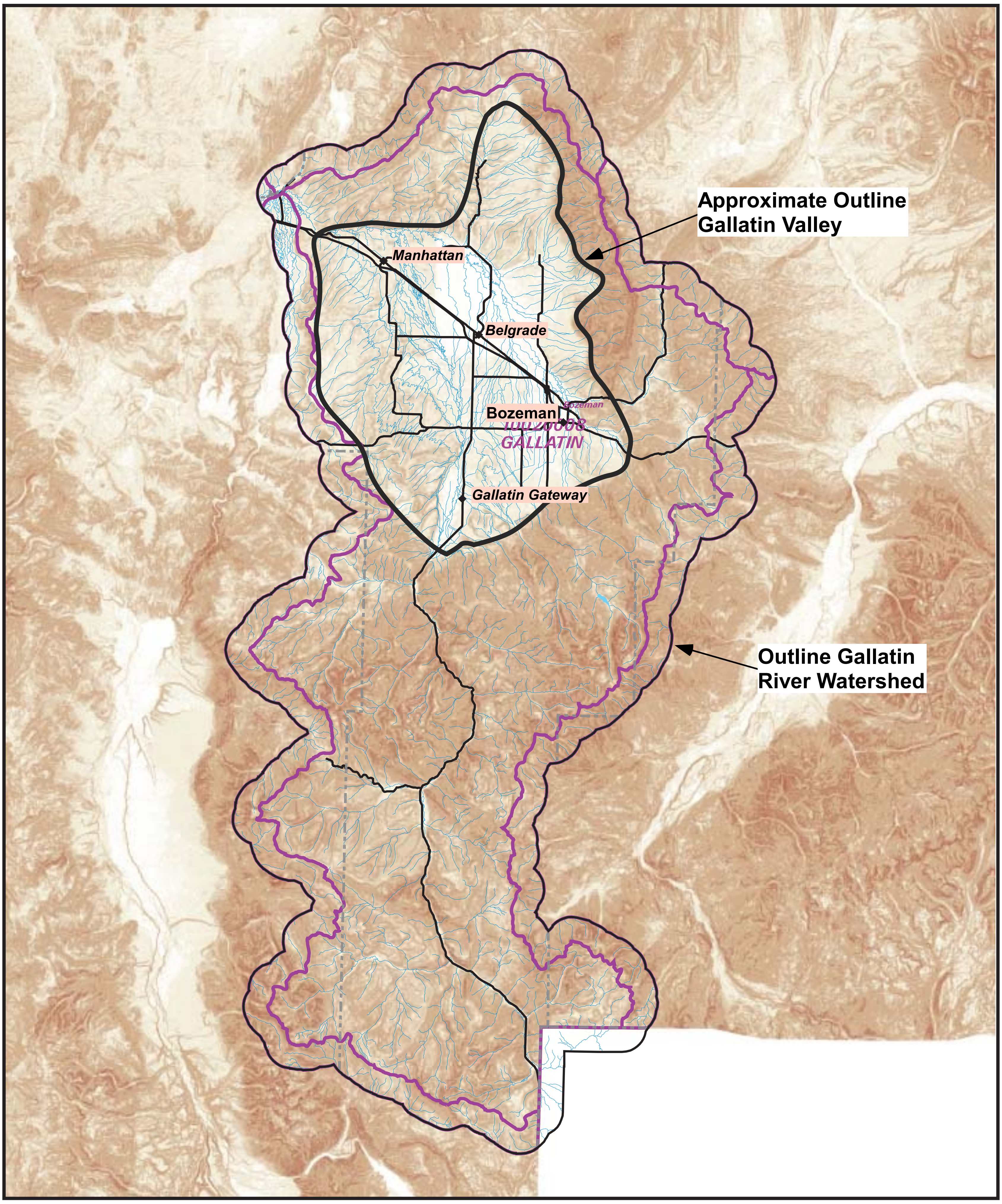
Date created: December 03, 2003

Map Request: 04MSL0001 - 10020008 - SLOPE

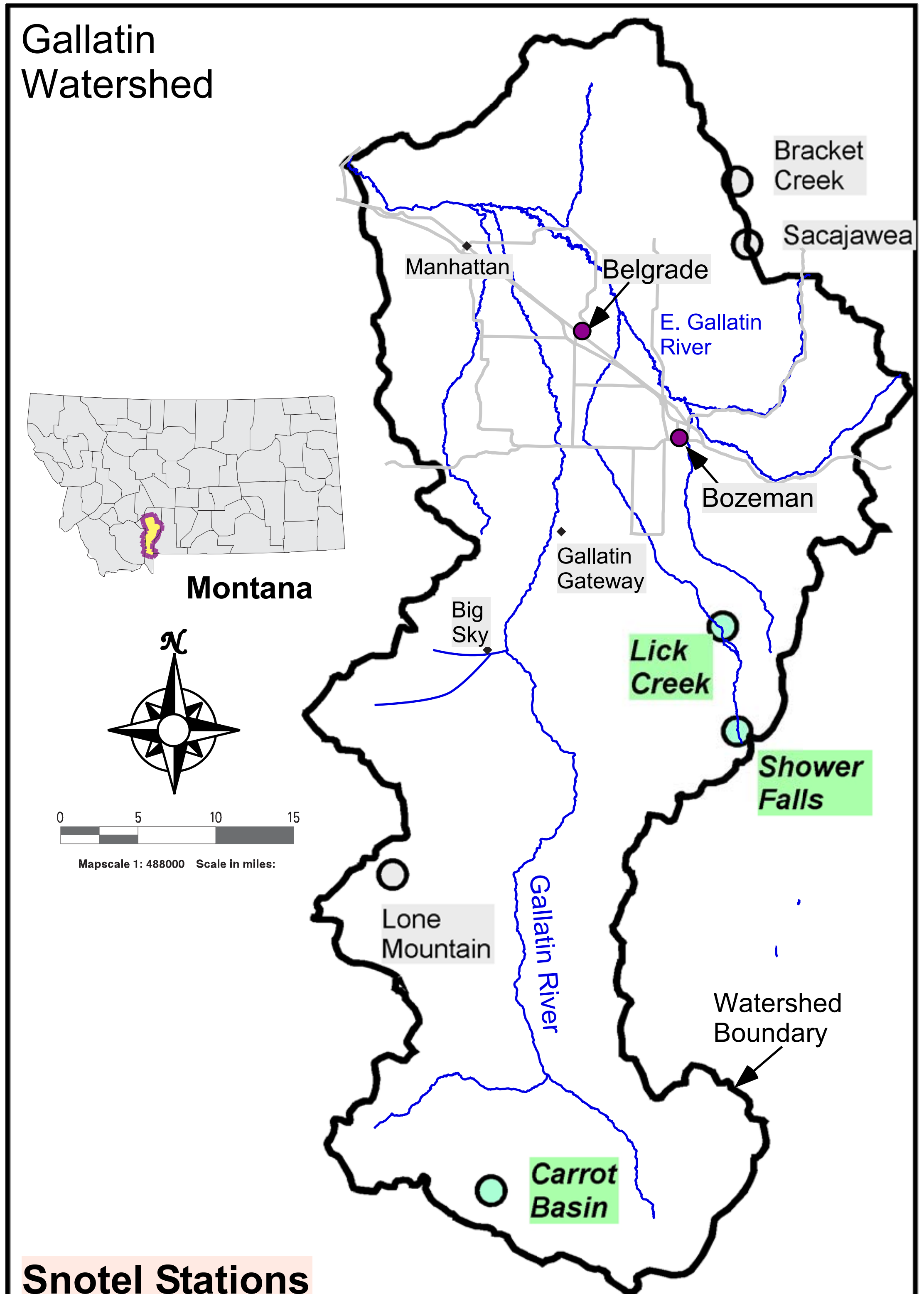
- County Border
- Highway
- Fourth Code Watersheds
- 0 < X < = 4
- 4 < X < = 10
- 10 < X < = 30
- 30 < X < = 45
- 45 < X < = 60
- 60 < X = 90
- Flat, 0

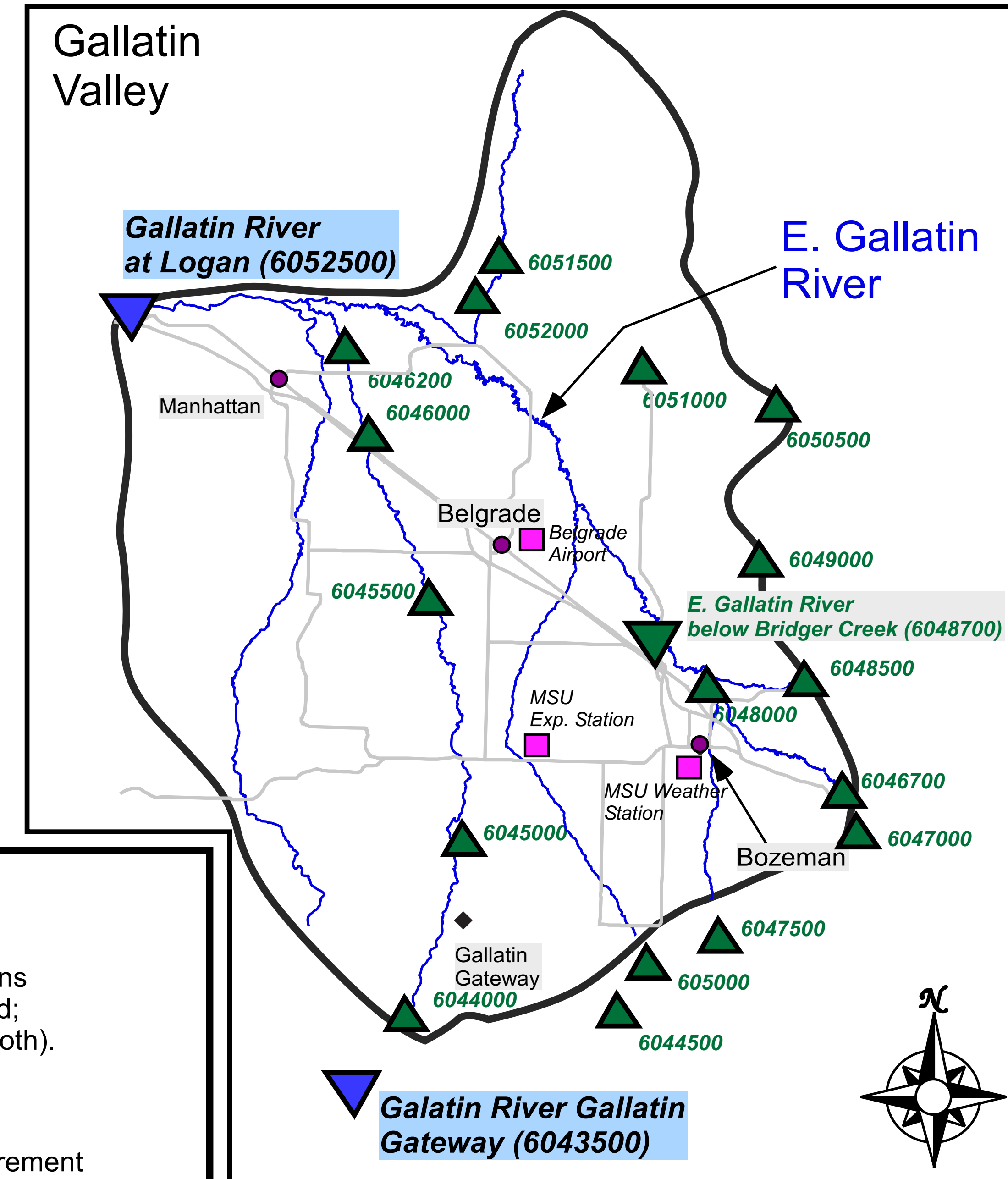
SOURCE:
US Geological Survey National Elevation Dataset (NED) files. NED has been developed by merging the highest resolution elevation data available for the United States into a seamless dataset. The slopes displayed are derived from the NED solely to illustrate one application of the dataset. This slope data is intended to display slope patterns, rather than a particular point of slope.

This map is to be used as a primary reference source and is not intended for use in site - specific planning. This is public information and may be interpreted by organizations, agencies, units of government, or others, based on needs; however,they are responsible for the appropriate application. Federal, State, or local regulatory bodies are not to reassign to the Natural Resource Information System any authority for the decisions they make.



January 4, 2007 c:\leg\gr\report\fig_02 Issued for Doney Law Firm	NICKLIN EARTH & WATER, INC.	Gallatin River Watershed Montana Natural Resource Information System	Figure 2

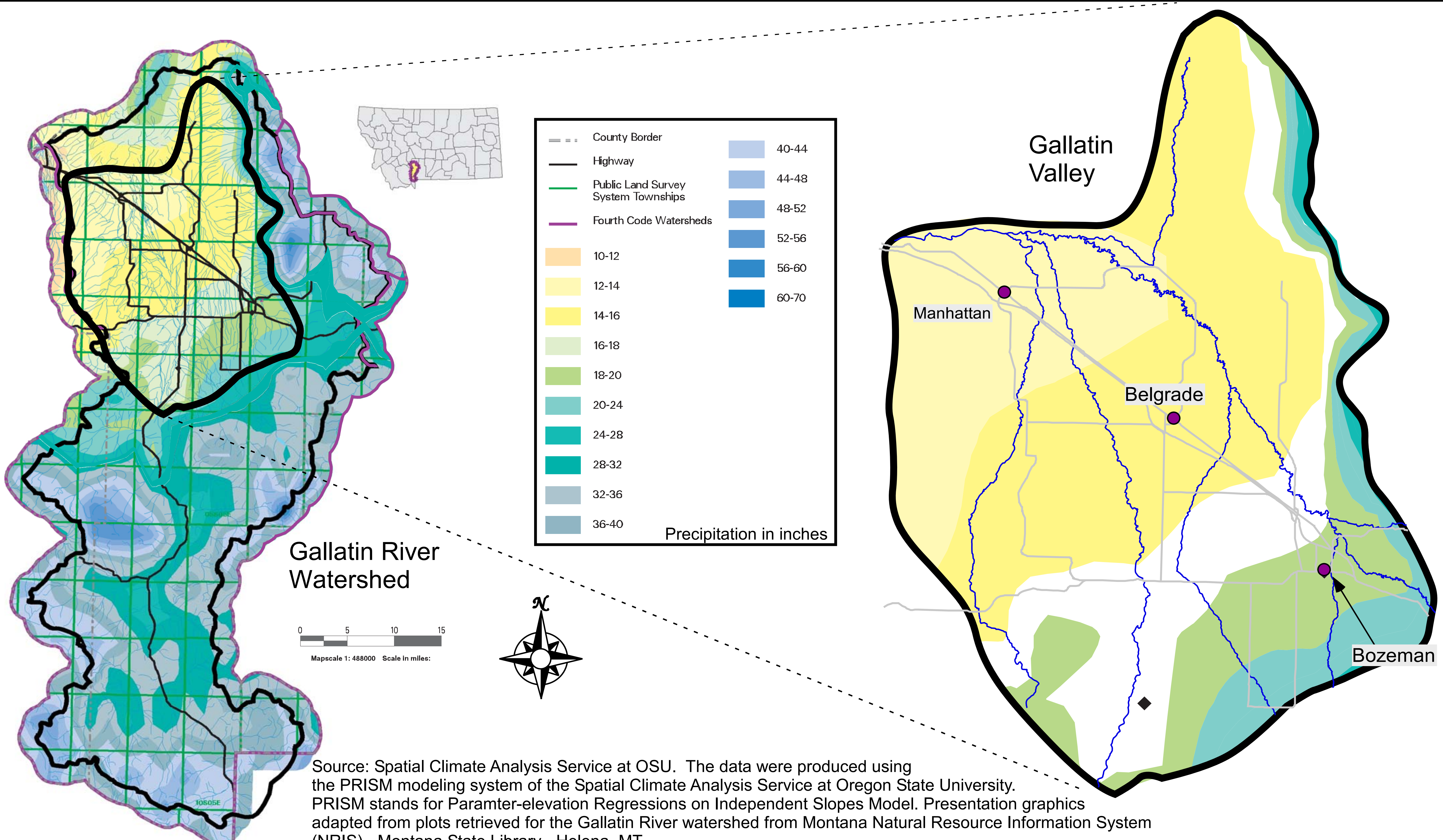




Legend

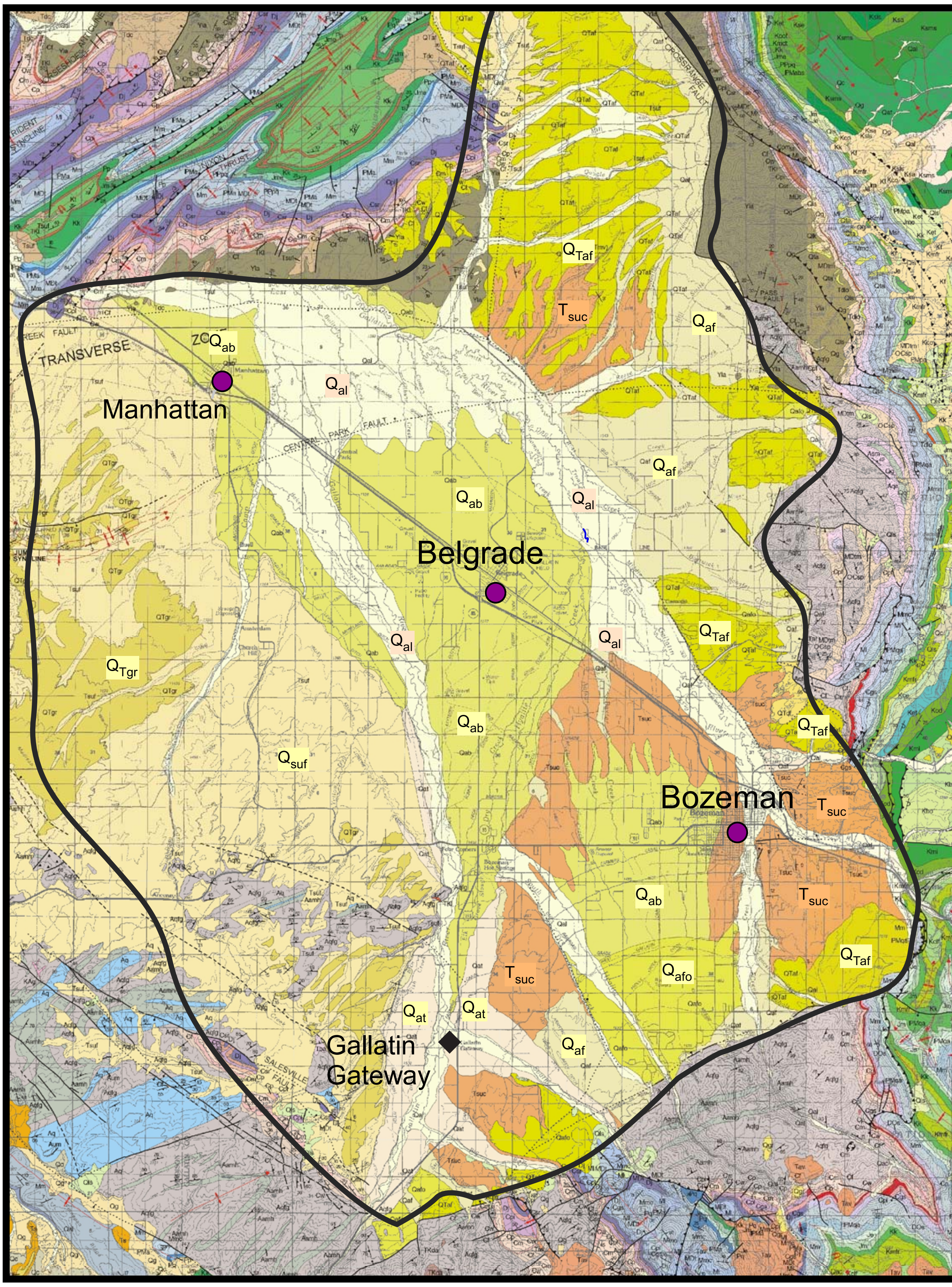
- Snotel Station Used for Report Evaluations
- Snotel Station Not Used for Report Evaluations (Either shorter term time measurement period; or high percentage of estimated values; or both).
- Weather Station
- Active gaging stations with extensive measurement record (used in analysis).
- Active gaging stations with brief measurement record.
- Inactive gaging stations with brief measurement record (many were part of an 1950s investigation conducted by the U.S. Geological Survey (Hackett, et al, 1960)).

Date: January 6, 2007 **File c:\leg\doney\gal\Fig_03** **Issued for Doney Law Firm**	NICKLIN EARTH & WATER, INC.	**Measurement Stations** **Gallatin Watershed and Gallatin Valley**	**Figure 3**



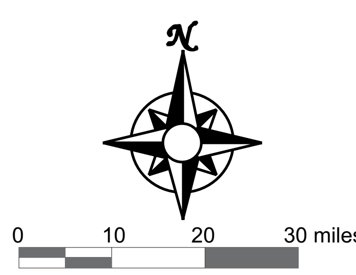
Source: Spatial Climate Analysis Service at OSU. The data were produced using the PRISM modeling system of the Spatial Climate Analysis Service at Oregon State University. PRISM stands for Paramter-elevation Regressions on Independent Slopes Model. Presentation graphics adapted from plots retrieved for the Gallatin River watershed from Montana Natural Resource Information System (NRIS) - Montana State Library - Helena, MT.

Date: January 6, 2007 **File c:\leg\gal\Fig_04** **Issued for Doney Law Firm**	NICKLIN EARTH & WATER, INC.	**Precipitation Distribution** **Gallatin Watershed and Gallatin Valley**	**Figure 4**



Dominant Gallatin Valley Geologic Facies

Qal	Alluvium (Holocene)
Qat	Alluvial terrace deposit (Holocene and Pleistocene)
Qaf	Alluvial fan deposit (Holocene and Pleistocene)
Qgr	Gravel deposits, undivided (Holocene and/or Pleistocene)
Qab	Alluvial braid plain deposit (Holocene? and Pleistocene)
Qat	Alluvial terrace deposit (Pleistocene)
Qafo	Older alluvial fan deposit (Pleistocene)
Qg	Glacial deposits, undivided (Pleistocene)
QTgr	Gravel deposits (Pleistocene, and/or Pliocene)
Qtaf	Alluvial fan deposit (Pleistocene and/or Pliocene)
Tsuf	Dominantly fine-grained facies (Miocene)
Tsuc	Dominantly coarse-grained facies (Miocene and Pliocene?)



Adapted from PRELIMINARY GEOLOGIC MAP OF THE BOZEMAN 30' x 60' QUADRANGLE SOUTHWESTERN MONTANA Compiled and mapped by Susan M. Vuke, Jeffrey D. Lonn, Richard B. Berg, and Karl S. Kellogg; Montana Bureau of Mines and Geology Open File Report MBMG 469, 2002.
GEOLOGIC MAP OF THE LIVINGSTON 30' x 60' QUADRANGLE SOUTH-CENTRAL MONTANA by Richard B. Berg, David A. Lopez, and Jeffrey D. Lonn, Montana Bureau of Mines and Geology Open File Report MBMG 406, 2000.

Date: January 6, 2007 **File: c:\leg\gal\fig_05** **Issued for Doney Law Firm**	NICKLIN EARTH & WATER, INC.	**Dominant Geologic Units** **Galley Valley**	**Figure 5**

Figure 6

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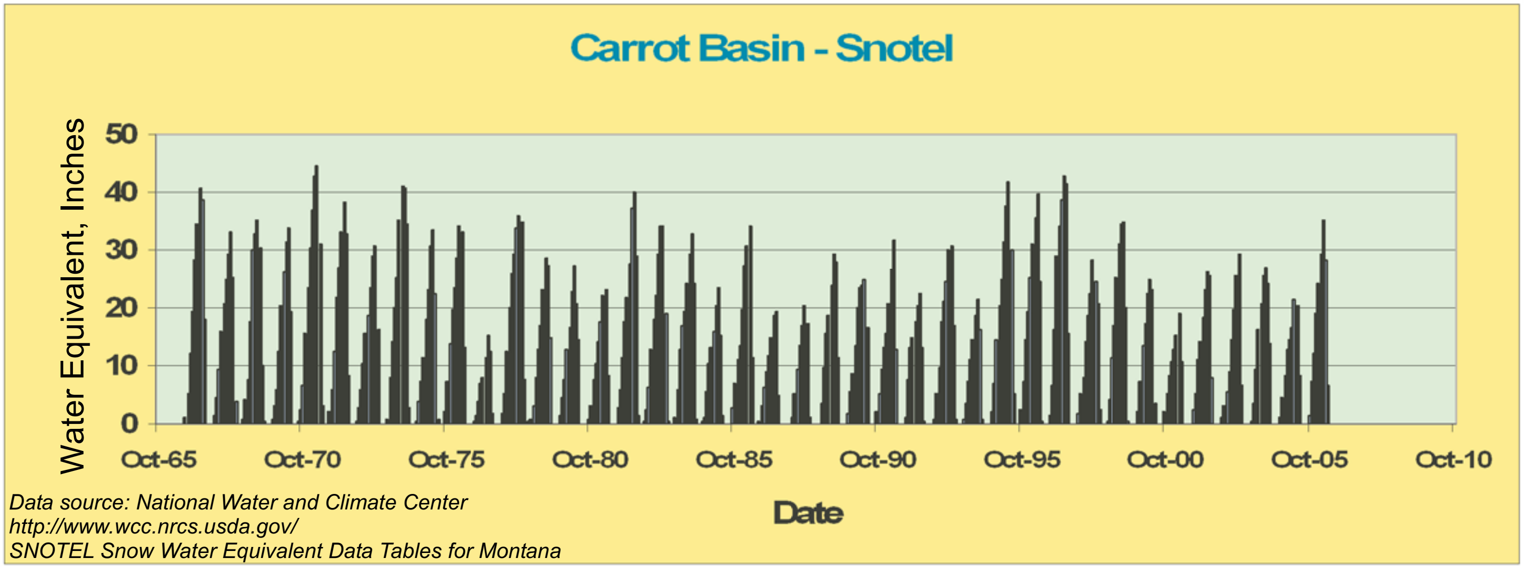
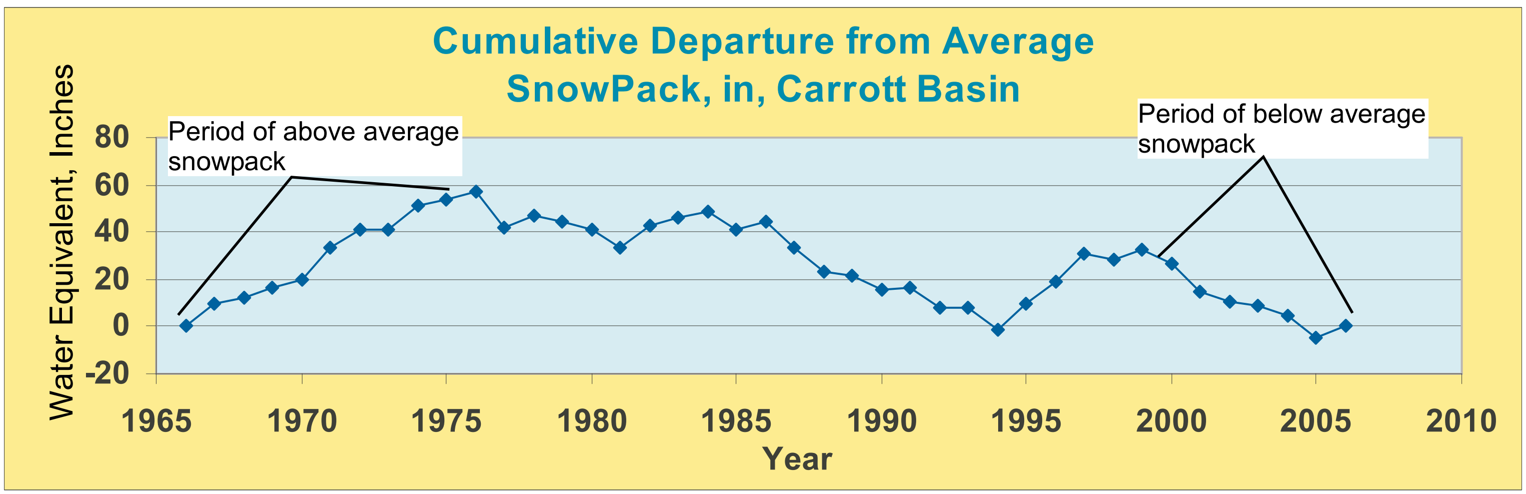
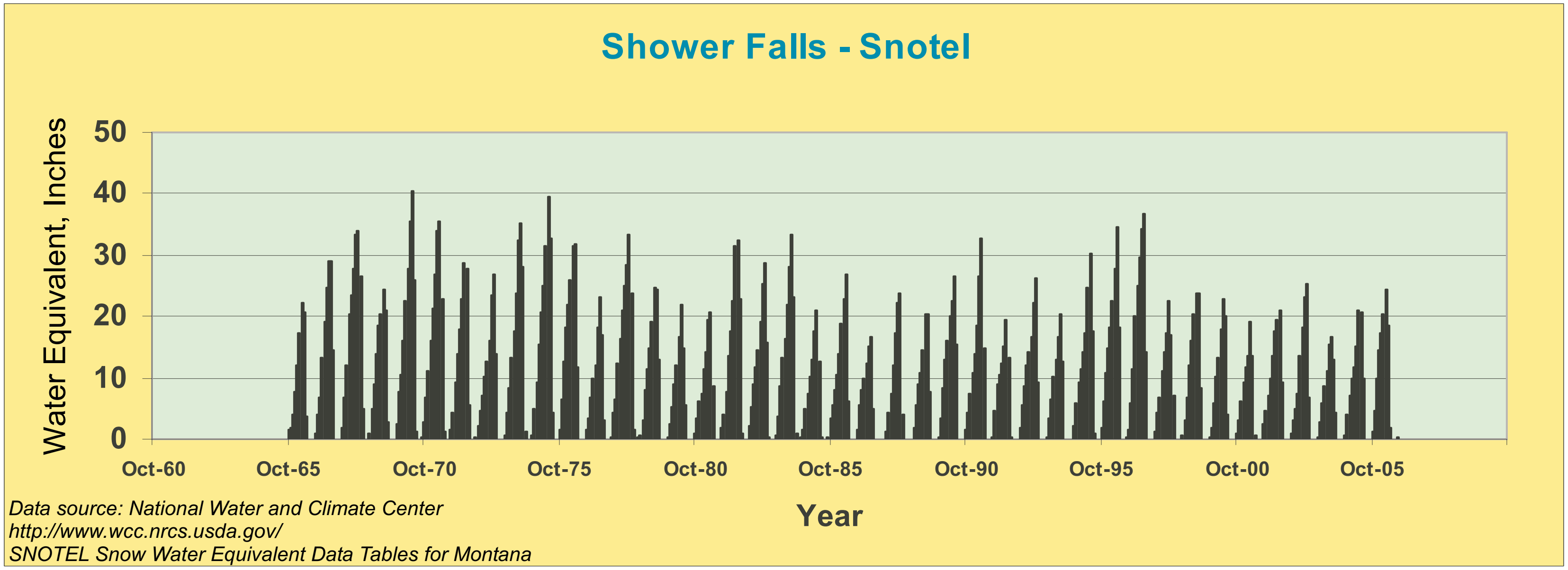
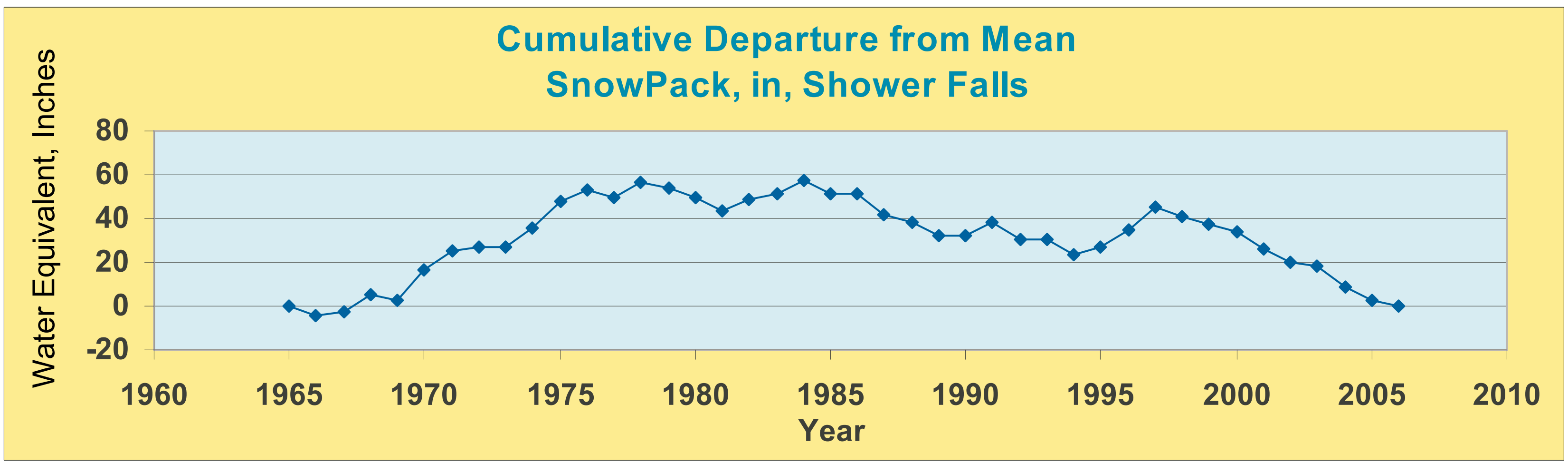




Note: For the cumulative departure from average plot, upward trends imply a longer periods of above average snowpack whereas downward trends imply a longer periods of below average snowpack (see examples above).

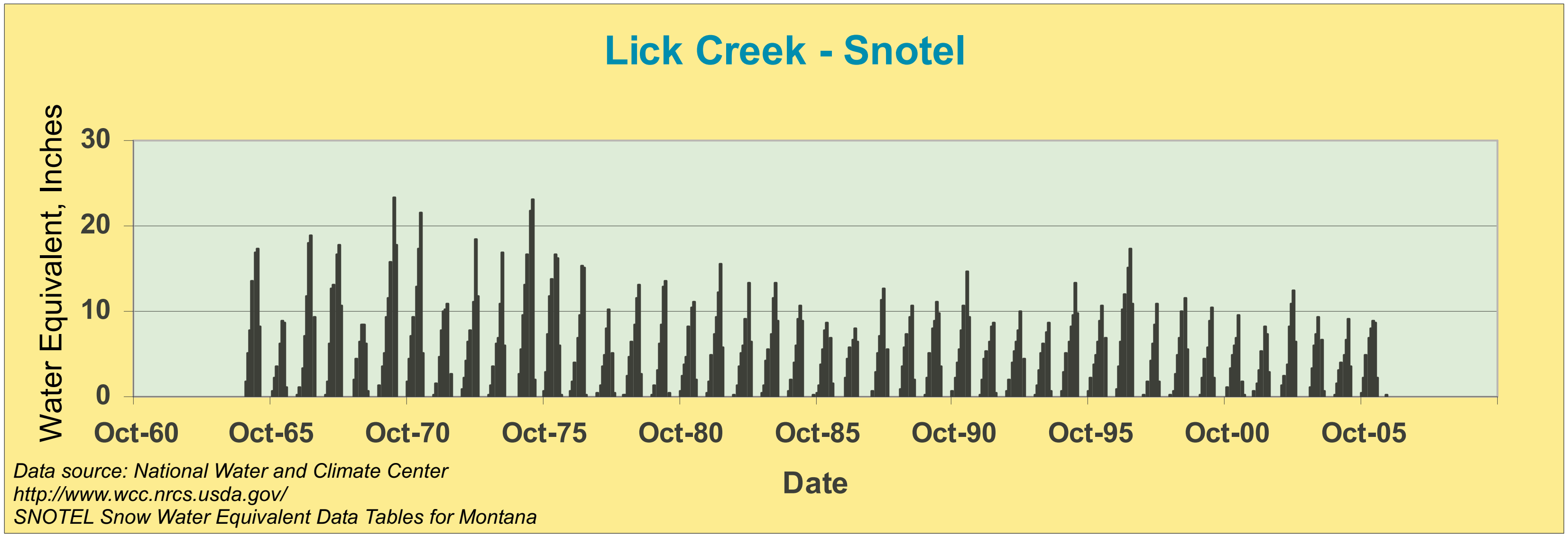
Date: 12/23/06 c:\leg\gal\rep\fig_7a For Doney Law Firm	NICKLIN EARTH & WATER, INC.	**Snotel Data Summary** **Carrot Basin**	**Figure 7a**

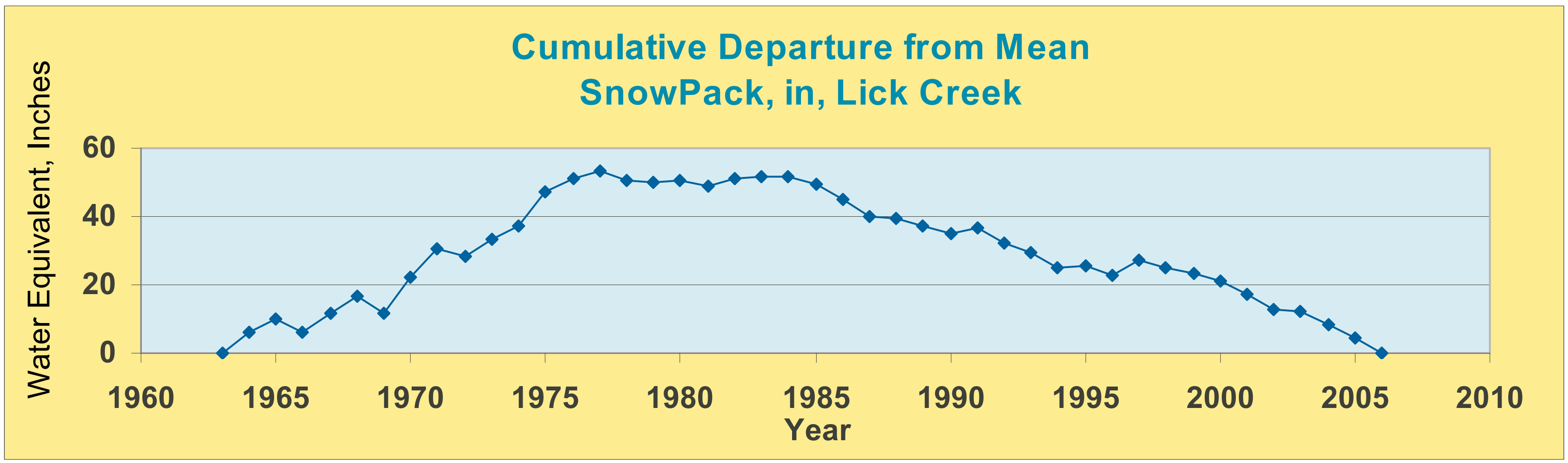




Note: For the cumulative departure from average plot, upward trends imply a longer periods of greater snowpack whereas downward trends imply a longer periods of lower snowpack.

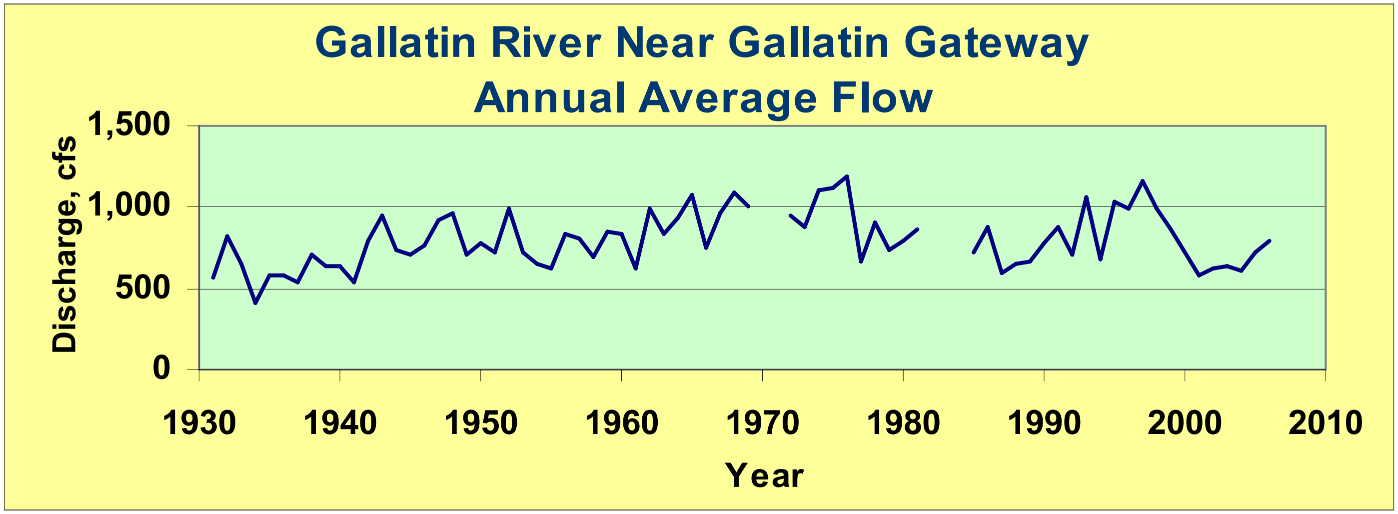
Date: 12/23/06 c:\leg\gal\rep\fig_7b For Doney Law Firm	NICKLIN EARTH & WATER, INC.	**Snotel Data Summary** **Shower Falls**	**Figure 7b**



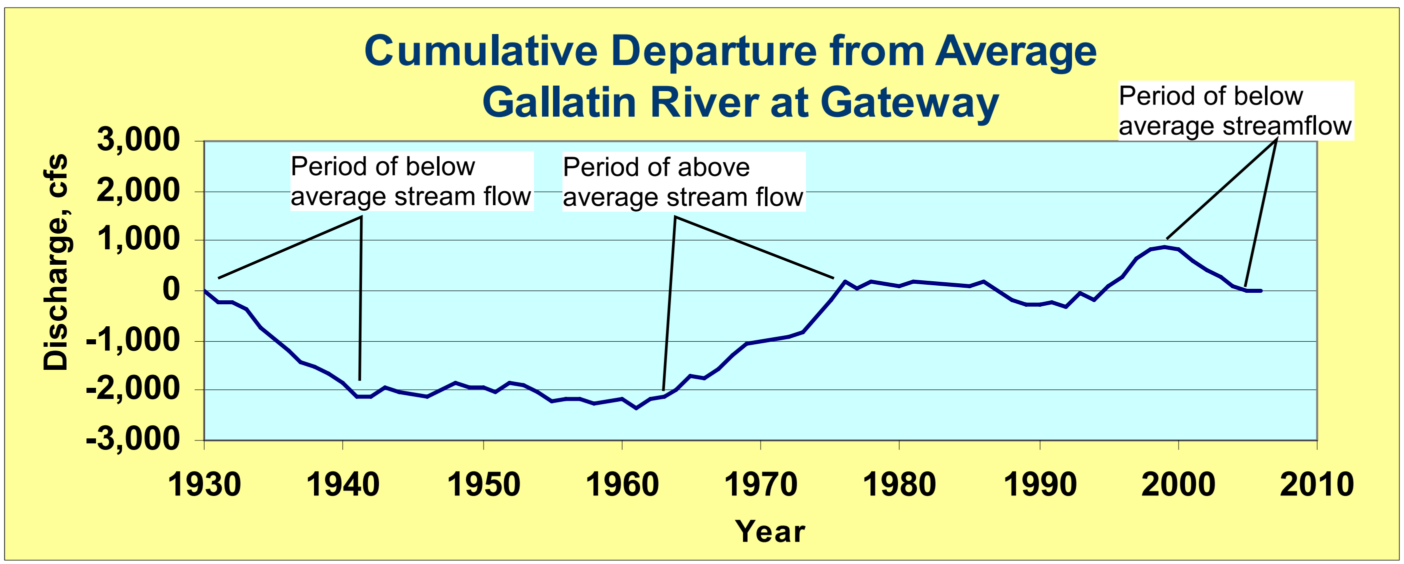


Note: For the cumulative departure from average plot, upward trends imply a longer periods of greater snowpack whereas downward trends imply a longer periods of lower snowpack.

Date: 12/23/06 c:\leg\gal\rep\fig_7c For Doney Law Firm	NICKLIN EARTH & WATER, INC.	**Snotel Data Summary** **Lick Creek**	**Figure 7c**

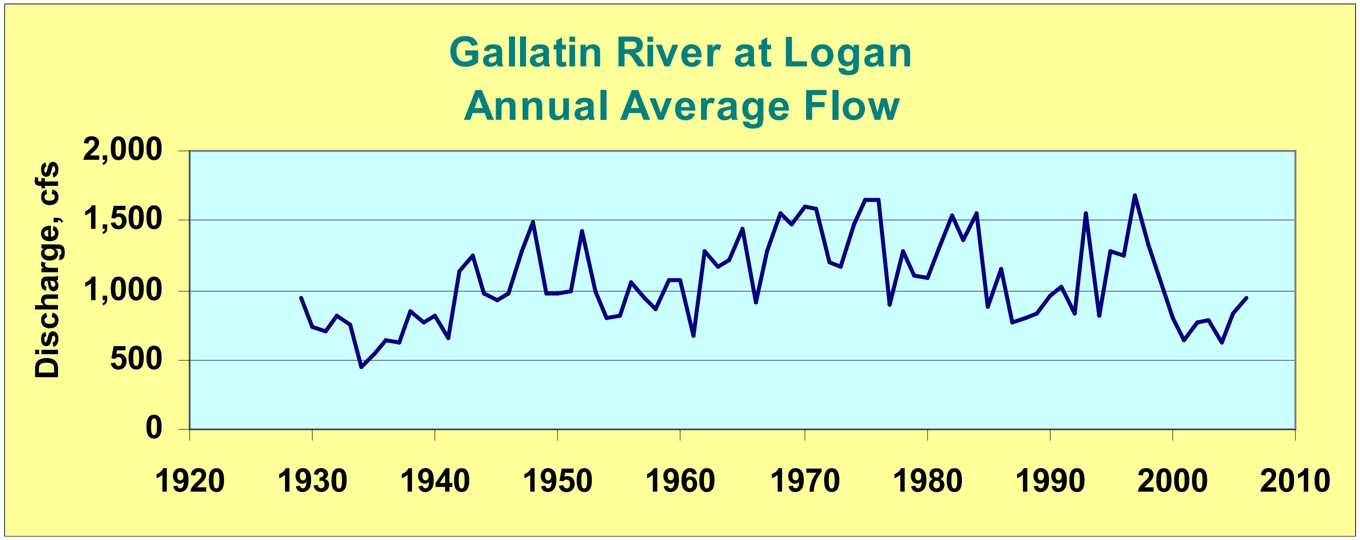


Data source: National Water Information System: Web Interface
http://nwis.waterdata.usgs.gov/

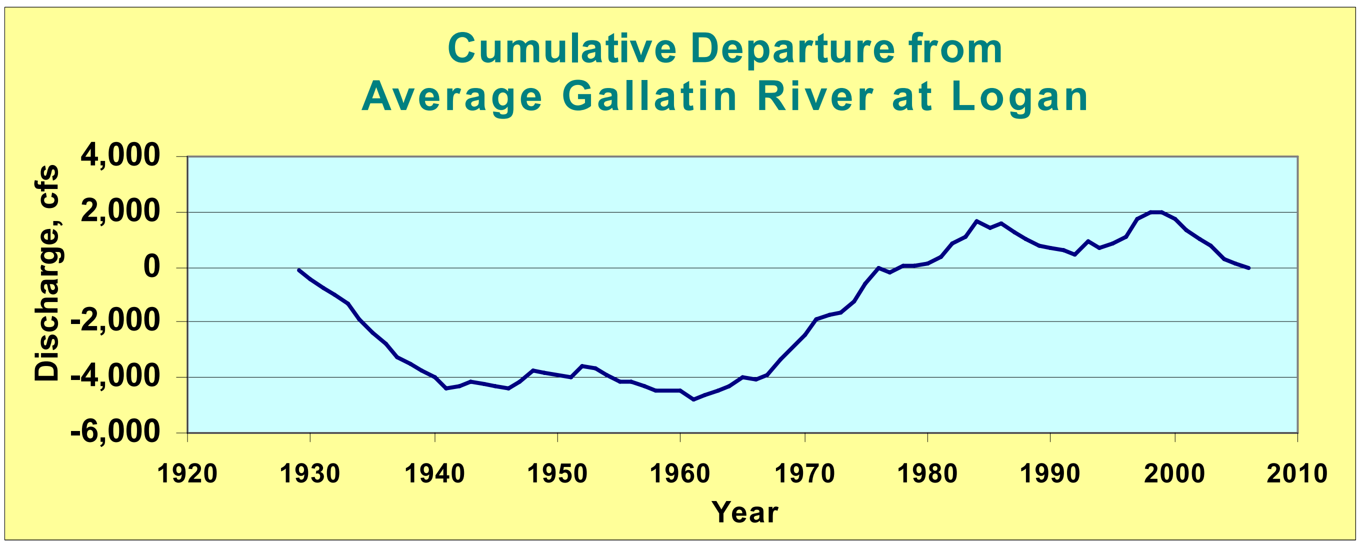


Note: For the cumulative departure from average plot, upward trends imply longer periods of below average stream flow whereas upward trends imply longer periods of average stream flow.

Date: 12/23/06 c:\leg\gal\rep\fig_8a For Doney Law Firm	NICKLIN EARTH & WATER, INC.	**Streamflow Discharge Gallatin River near Gallatin Gateway**	**Figure 8a**

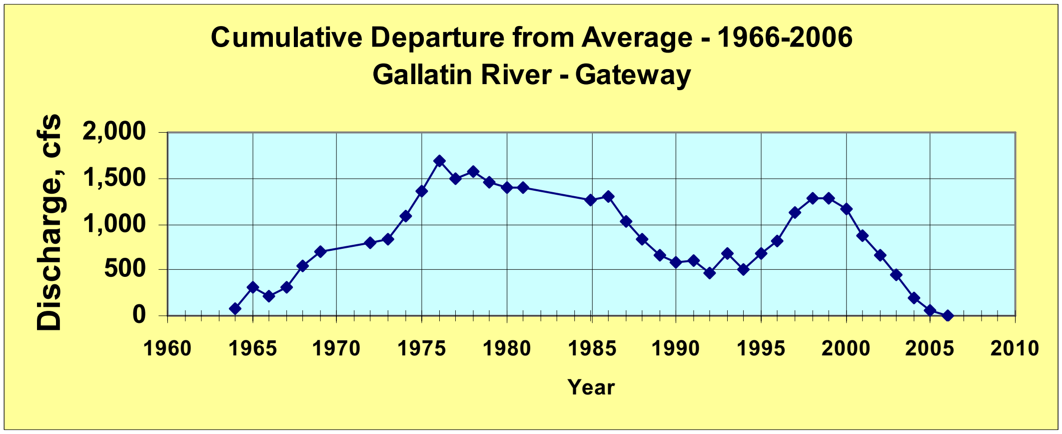


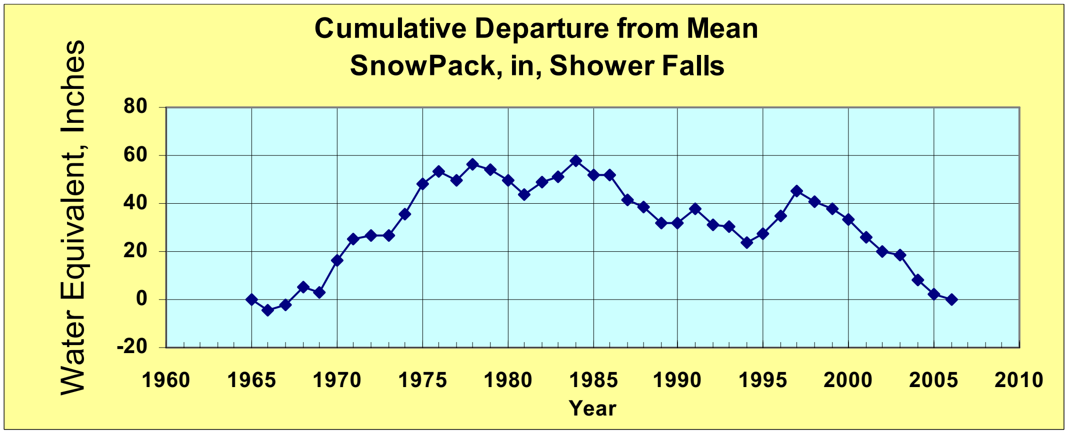
Data source: National Water Information System: Web Interface
http://nwis.waterdata.usgs.gov/

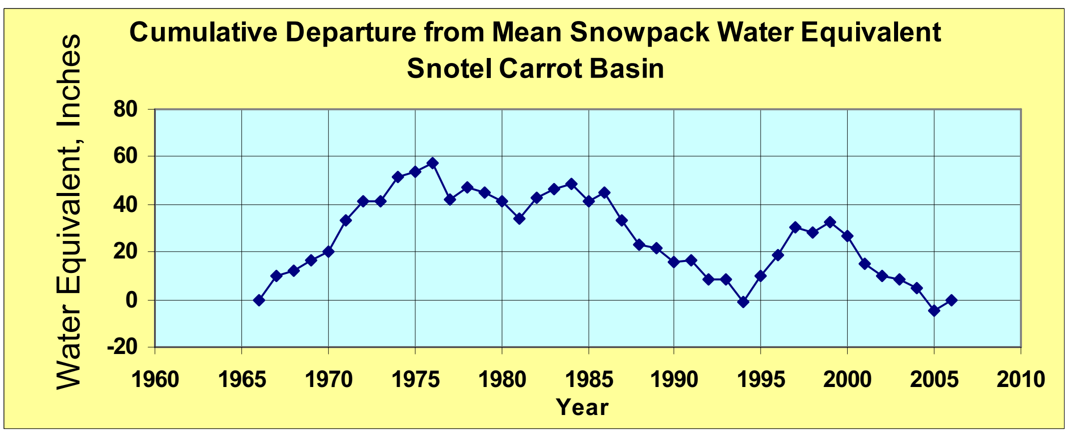


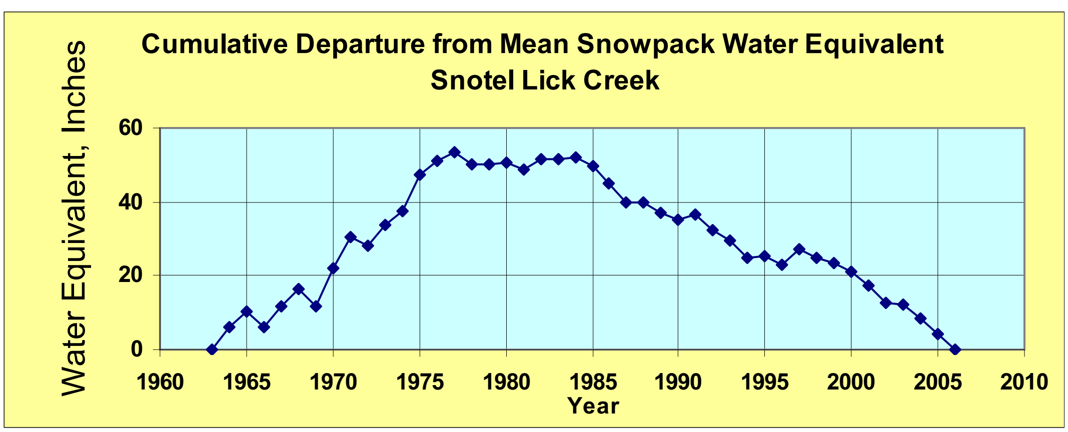
Note: For the cumulative departure from average plot, upward trends imply longer periods of below average stream flow whereas upward trends imply longer periods of average stream flow.

Date: 12/23/06 c:\leg\gal\rep\fig_8b For Doney Law Firm	NICKLIN EARTH & WATER, INC.	**Streamflow Discharge Gallatin River at Logan**	**Figure 8b**

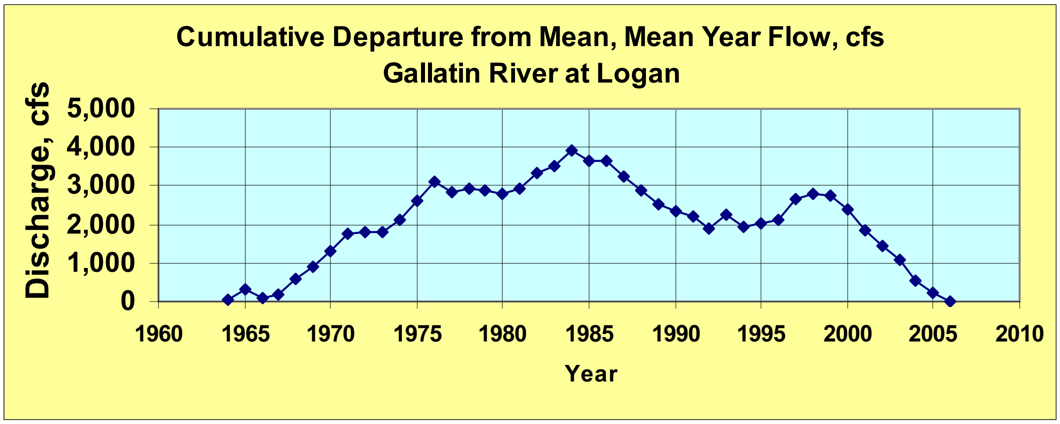


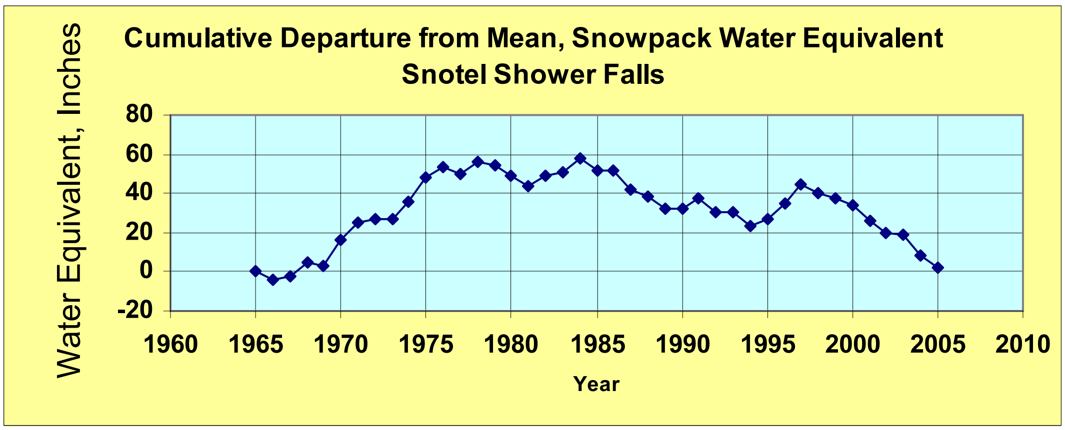


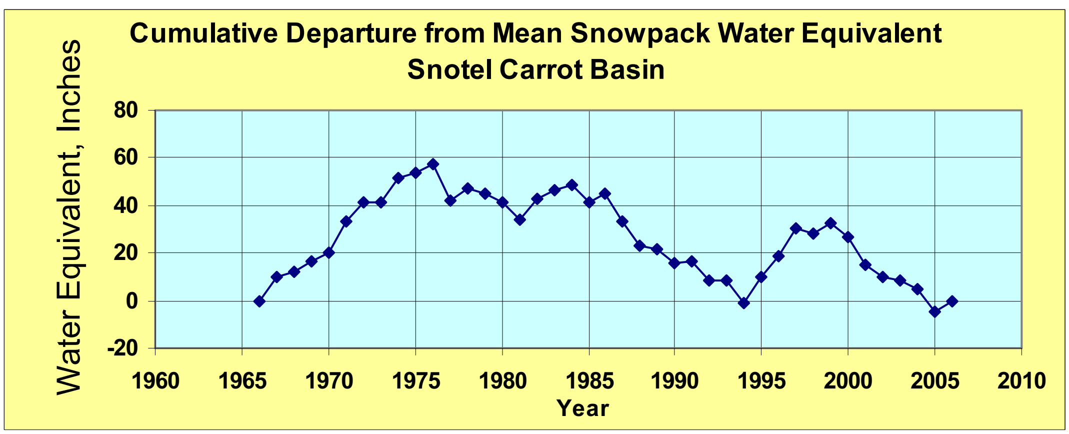


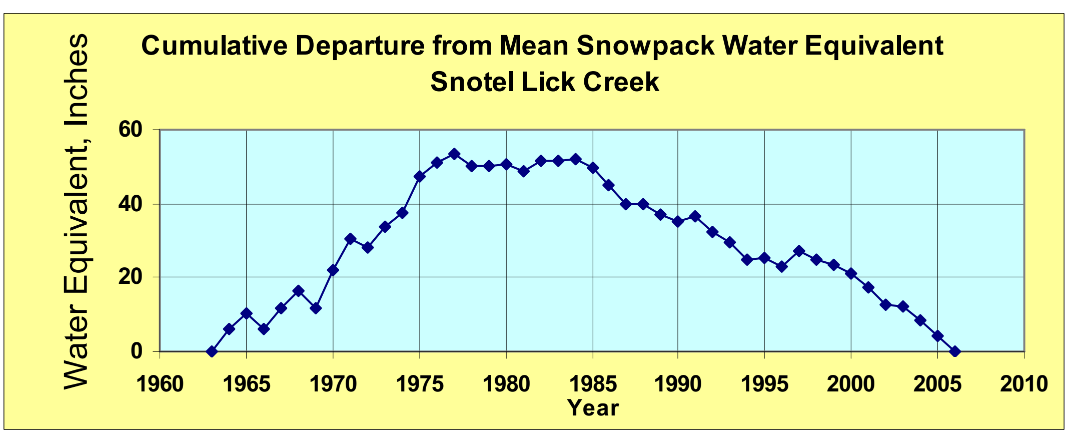


Date: 12/23/06 c:\leg\gal\rep\fig_9a For Doney Law Firm	NICKLIN EARTH & WATER, INC.	Gallatin River near Gateway Flow Versus Snotel Stations	Figure 9a

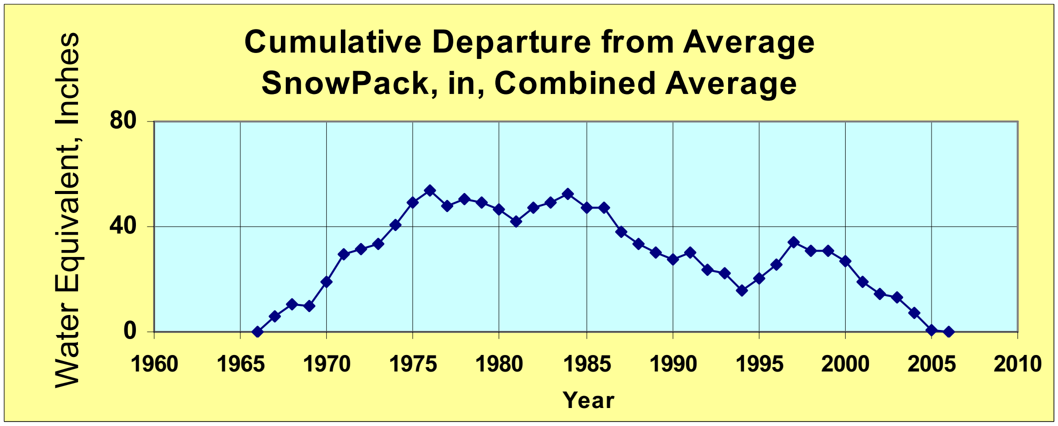


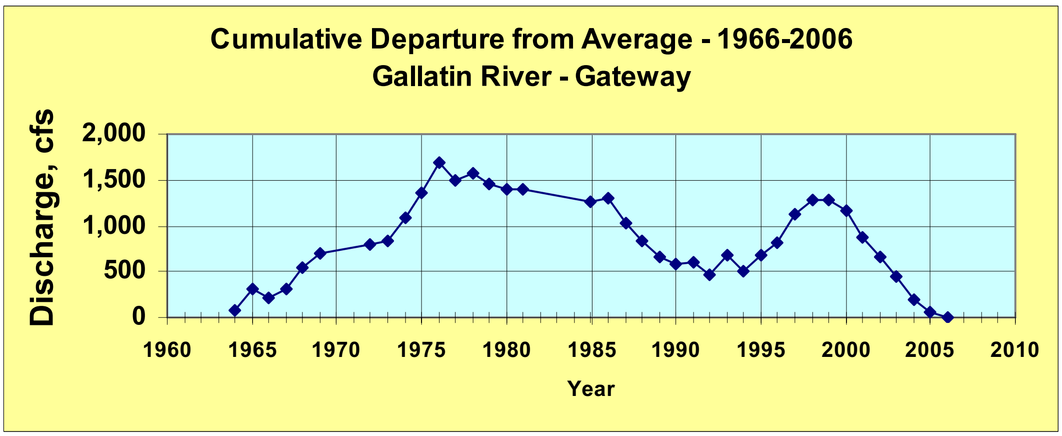


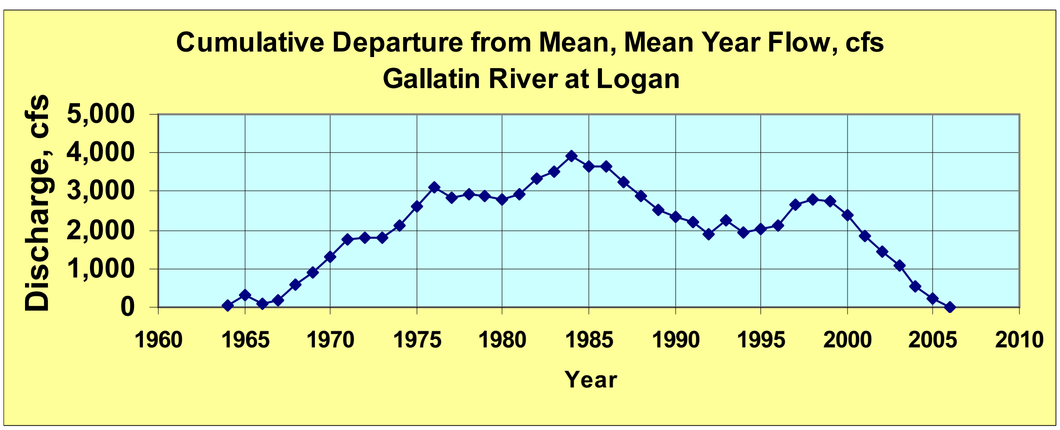




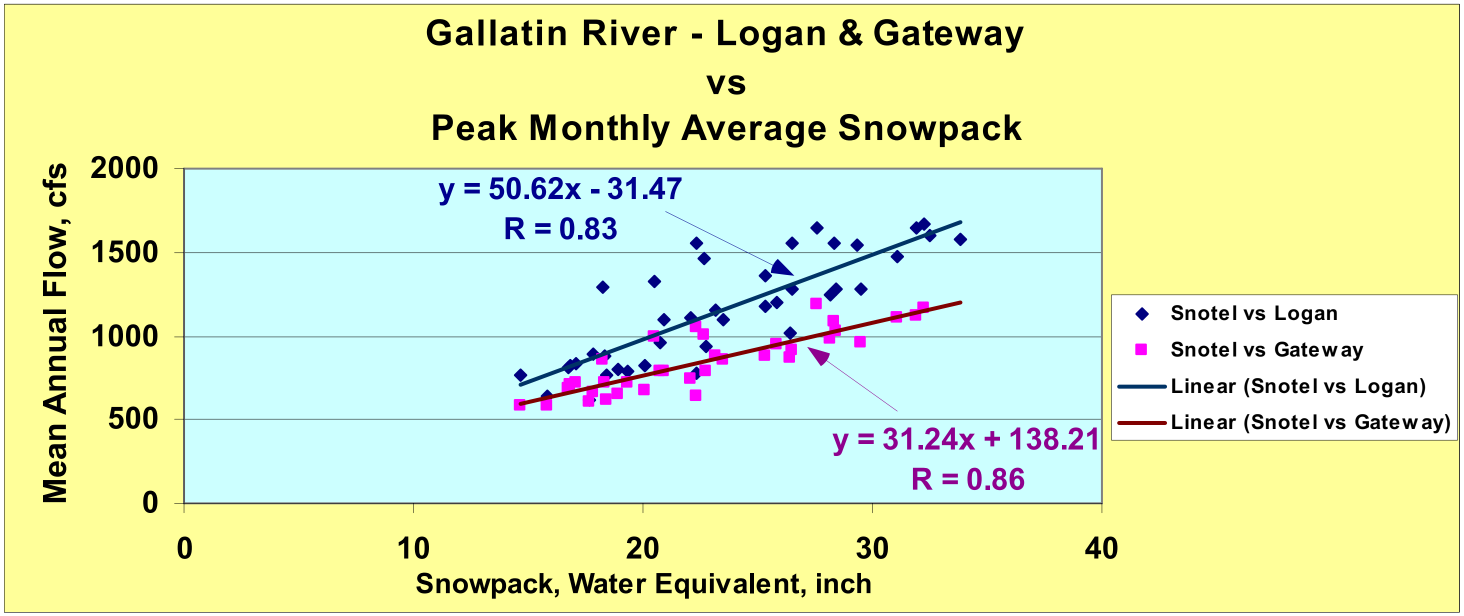
Date: 12/23/06 c:\leg\gal\rep\fig_9b For Doney Law Firm	NICKLIN EARTH & WATER, INC.	Gallatin River at Logan Versus Snotel Stations	Figure 9b



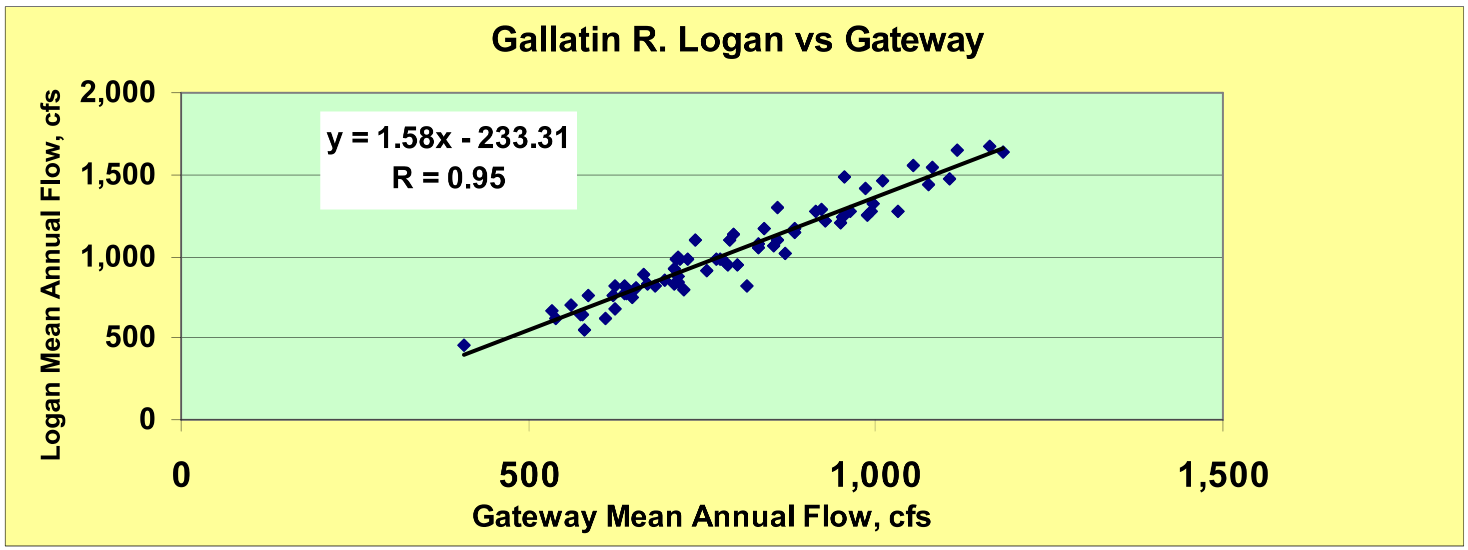




Date: 12/23/06 c:\leg\gal\rep\fig_9c For Doney Law Firm	NICKLIN EARTH & WATER, INC.	Gallatin River at Logan Versus Combined Snotel Stations	Figure 9c

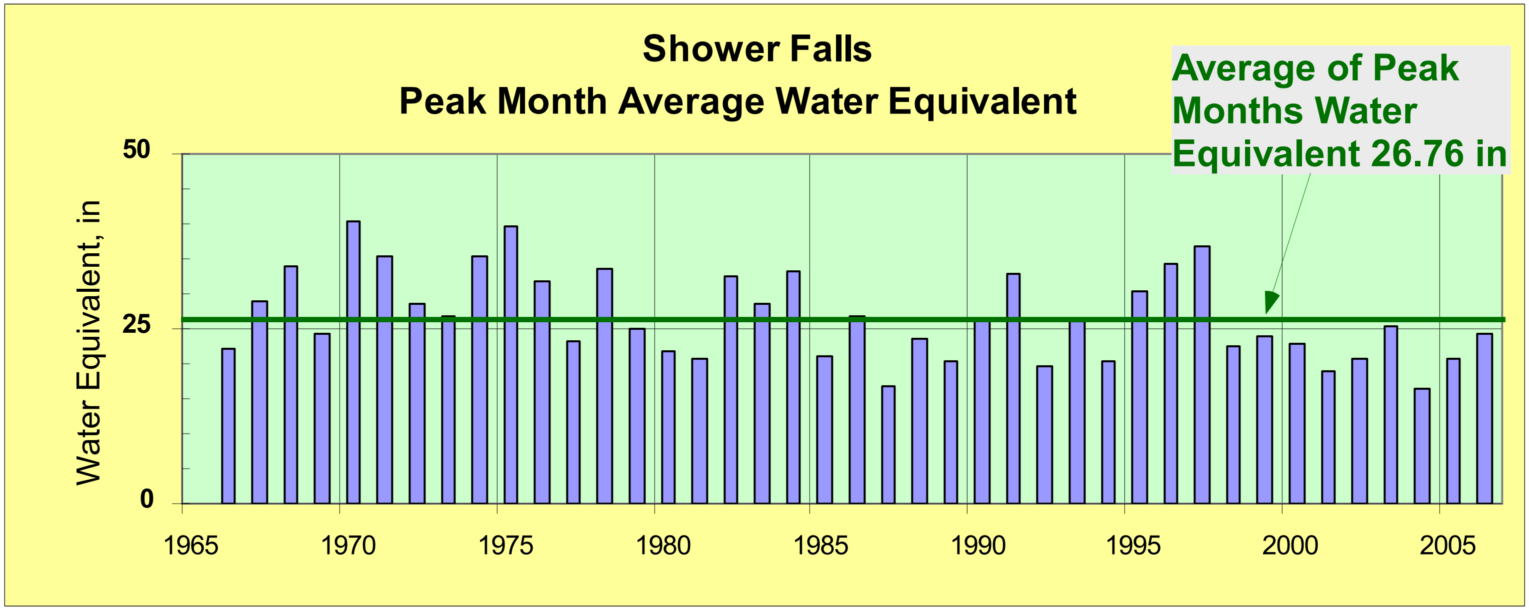


Uses Snotel and flow data from 1966 to 2006



Uses annual flow data from 1931 to 2006

Date: 12/23/06 c:\leg\gal\rep\fig_10 For Doney Law Firm	NICKLIN EARTH & WATER, INC.	**Regression Fits of Gallatin River Flow vs Snowpack**	**Figure 10**

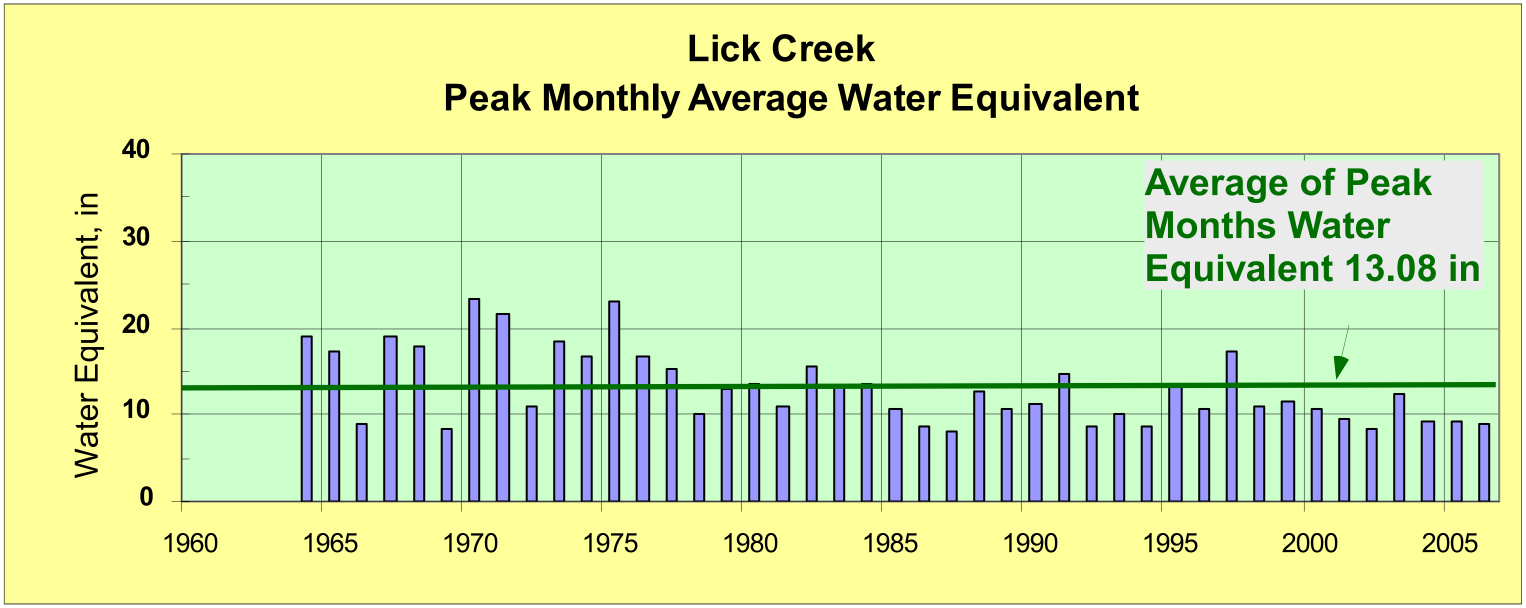


Number of years exceeding given snow water equivalent

	Exceeds 30 inches			Exceeds 25 inches			Exceeds 20 inches	
1960s	**1**	**4**		**2**	**4**		**4**	**4**
1970s	**6**	**10**		**8**	**10**		**10**	**10**
1980s	2	10		4	10		9	10
1990s	4	10		6	10		9	10
2000s	**0**	**7**		**1**	**7**		**5**	**7**

Note that the frequency of events for snowpack water equivalent to exceed 25 to 30 inches is substantially less in the last seven years versus other years.

Date: 12/23/06 c:\leg\gal\rep\fig_11a For Doney Law Firm	NICKLIN EARTH & WATER, INC.	**Exceedance Plot Evaluation of Snowpack for Shower Falls - Period of Record**	**Figure 11a**

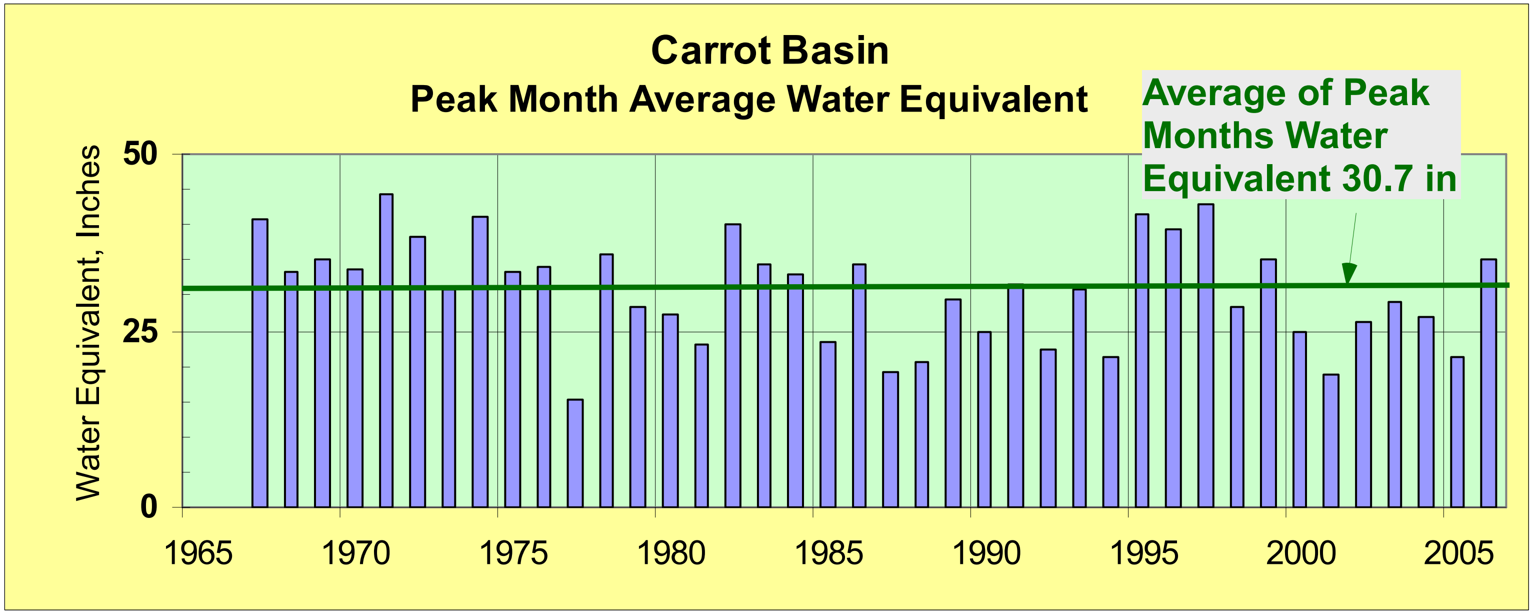


Number of years exceeding given snow water equivalent

	Exceeds 20 inches			Exceeds 15 inches			Exceeds 10 inches	
1960s	0	5		3	5		4	6
1970s	**3**	**10**		**7**	**10**		**10**	**10**
1980s	0	10		1	10		8	10
1990s	0	10		0	10		8	10
2000s	**0**	**7**		**0**	**7**		**2**	**7**

Note that the frequency of events for snowpack water equivalent to exceed 10 to 15 inches is substantially less in the last seven years versus other years.

Date: 12/23/06 c:\leg\gal\rep\fig_11b For Doney Law Firm	NICKLIN EARTH & WATER, INC.	**Exceedance Plot Evaluation of Snowpack for Lick Creek - Period of Record**	**Figure 11b**

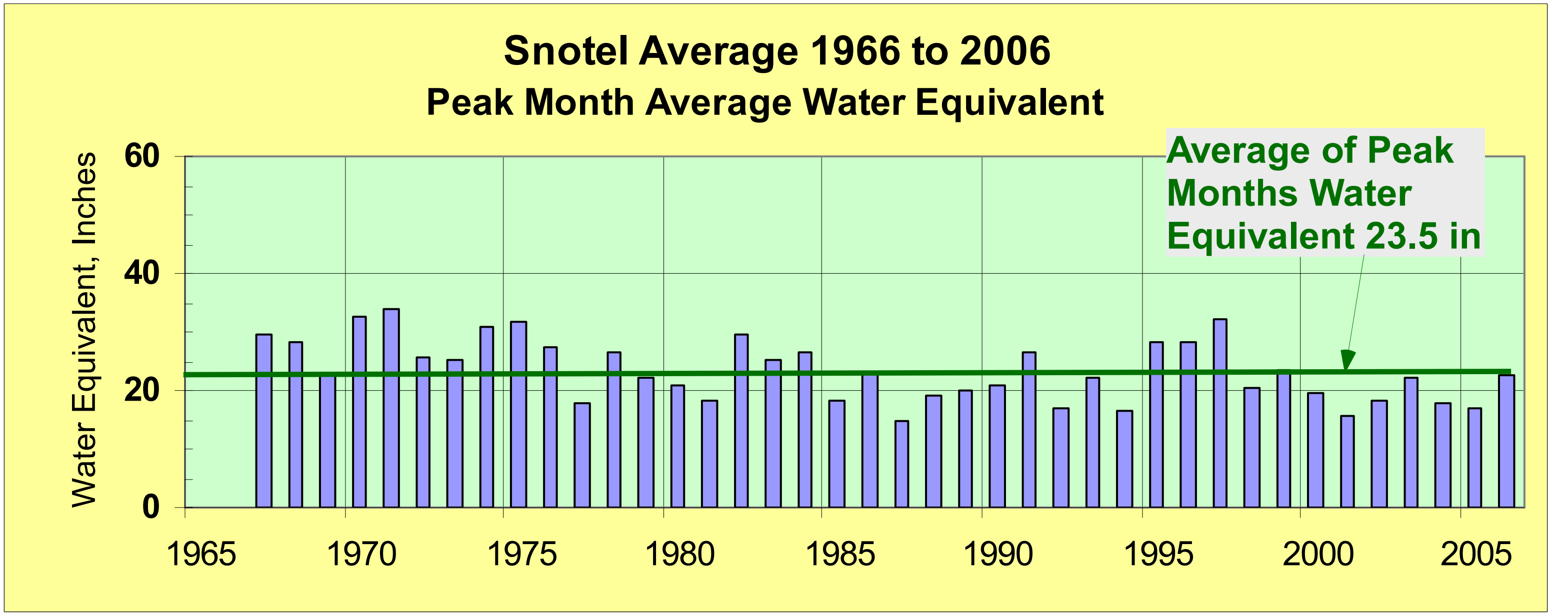


Number of years exceeding given snow water equivalent

	Exceeds 40 inches			Exceeds 30 inches			Exceeds 25 inches	
1960s	1	3		3	3		3	3
1970s	**2**	**10**		**8**	**10**		**9**	**10**
1980s	0	10		4	10		6	10
1990s	2	10		6	10		7	10
2000s	0	7		1	7		4	7

Note that the frequency of events for snowpack water equivalent to exceed 30 inches is substantially less in the last seven years versus other years.

Date: 12/23/06 c:\leg\gal\rep\fig_11c For Doney Law Firm	NICKLIN EARTH & WATER, INC.	**Exceedance Plot Evaluation of Snowpack for Carrot Basin - Period of Record**	**Figure 11c**

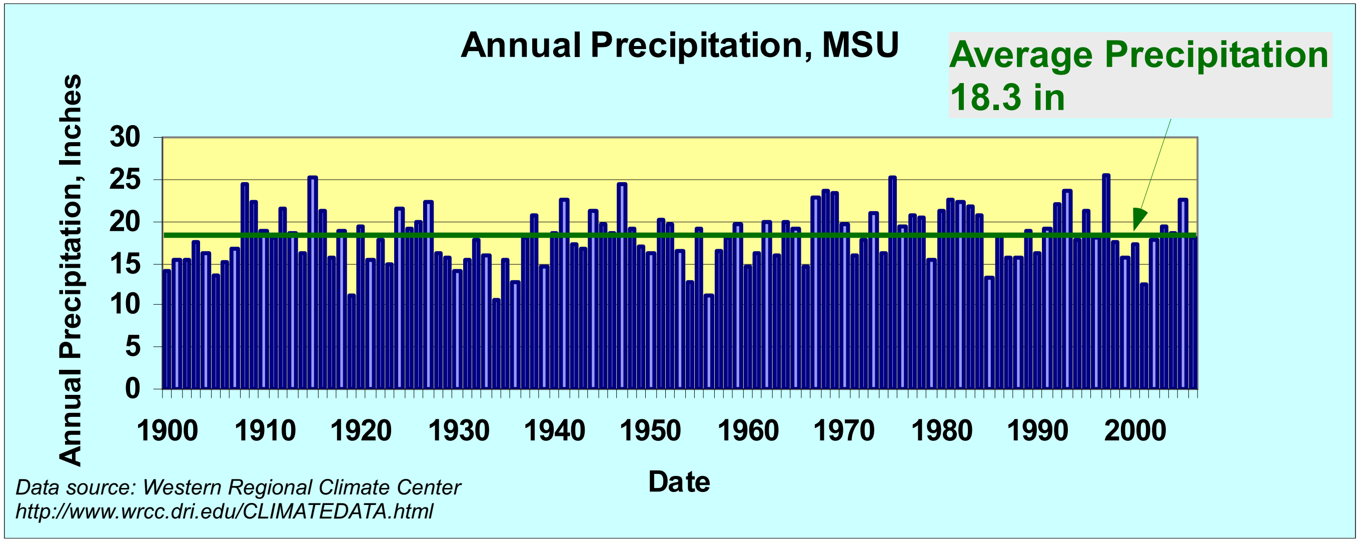


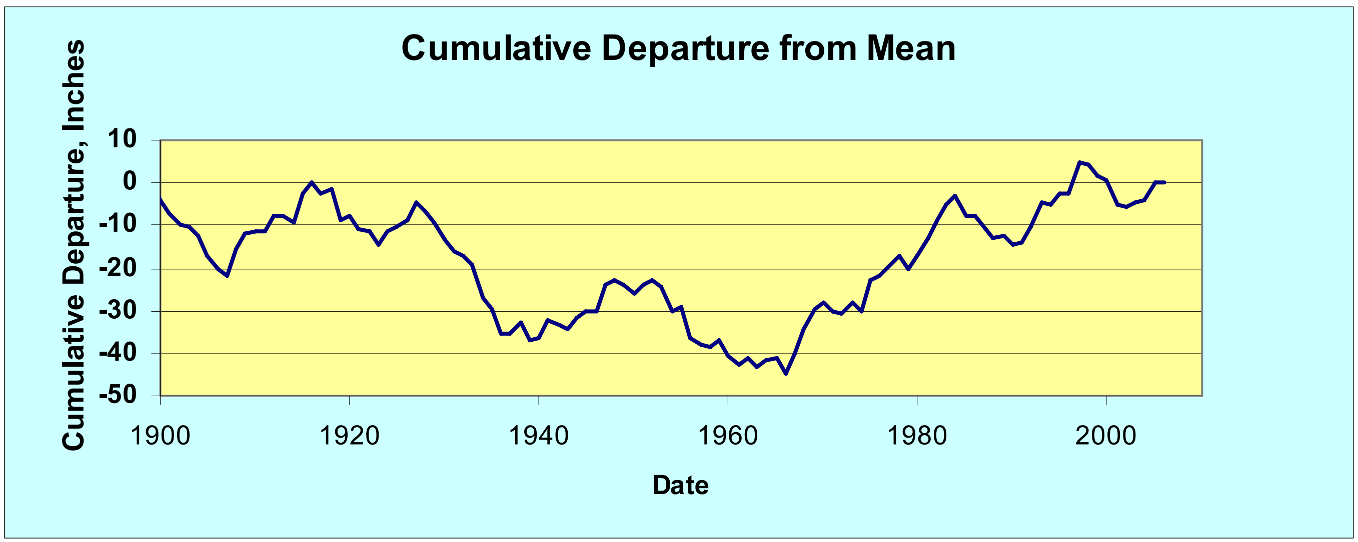
Number of years exceeding given snow water equivalent

	Exceeds 30 inches			Exceeds 25 inches			Exceeds 20 inches	
1960s	0	3		2	3		3	3
1970s	**4**	**10**		**8**	**10**		**9**	**10**
1980s	0	10		3	10		6	10
1990s	1	10		4	10		8	10
2000s	**0**	**7**		**0**	**7**		**2**	**7**

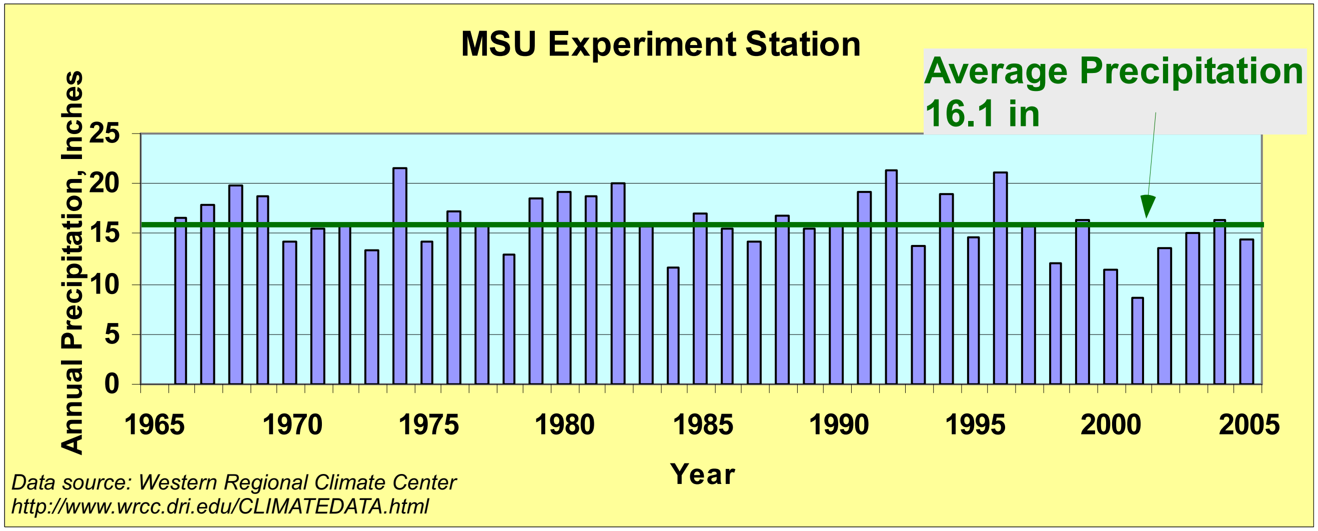
Note that the frequency of events for snowpack water equivalent to exceed 20 and 25 inches is substantially less in the last seven years versus other years.

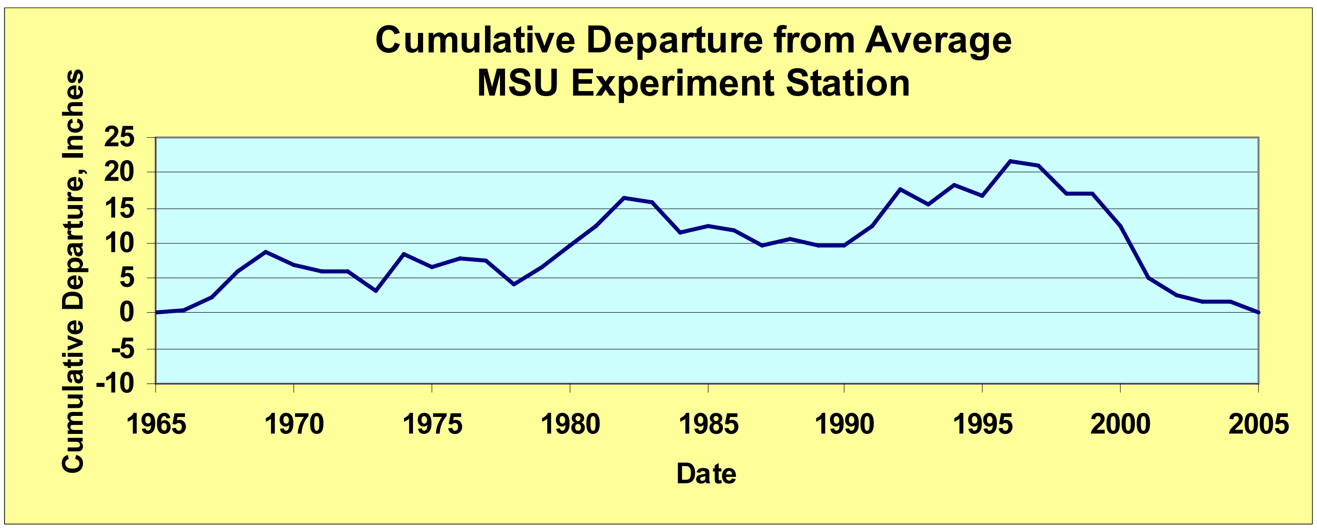
Date: 12/23/06 c:\leg\gal\rep\fig_11d For Doney Law Firm	NICKLIN EARTH & WATER, INC.	**Exceedance Plot Evaluation of Composited Snowpack - Period of Record**	**Figure 11d**



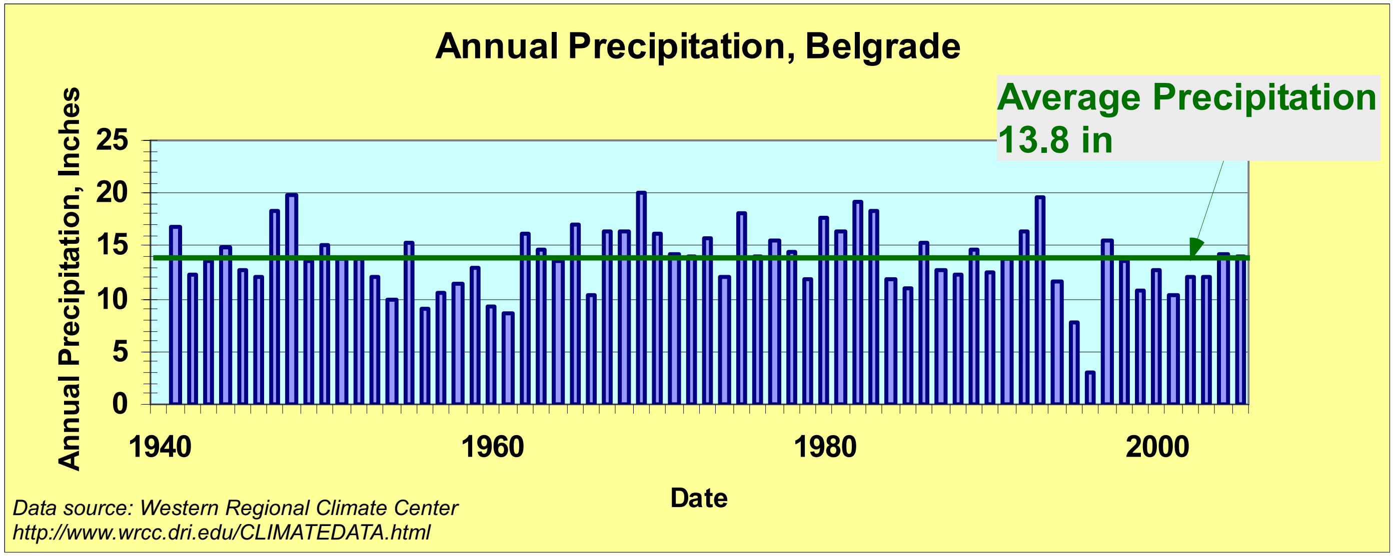


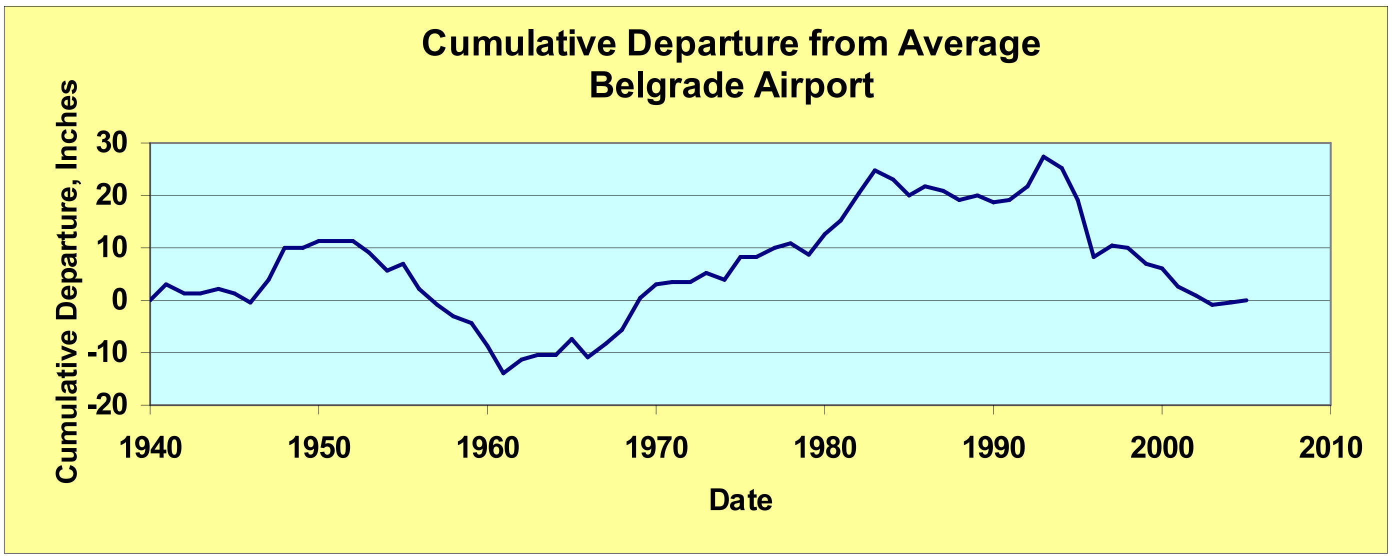
Date: 12/23/06 c:\leg\gal\rep\fig_12a For Doney Law Firm	NICKLIN EARTH & WATER, INC.	**Annual Precipitation and Cumulative Departure from Average Montana State University**	**Figure 12a**



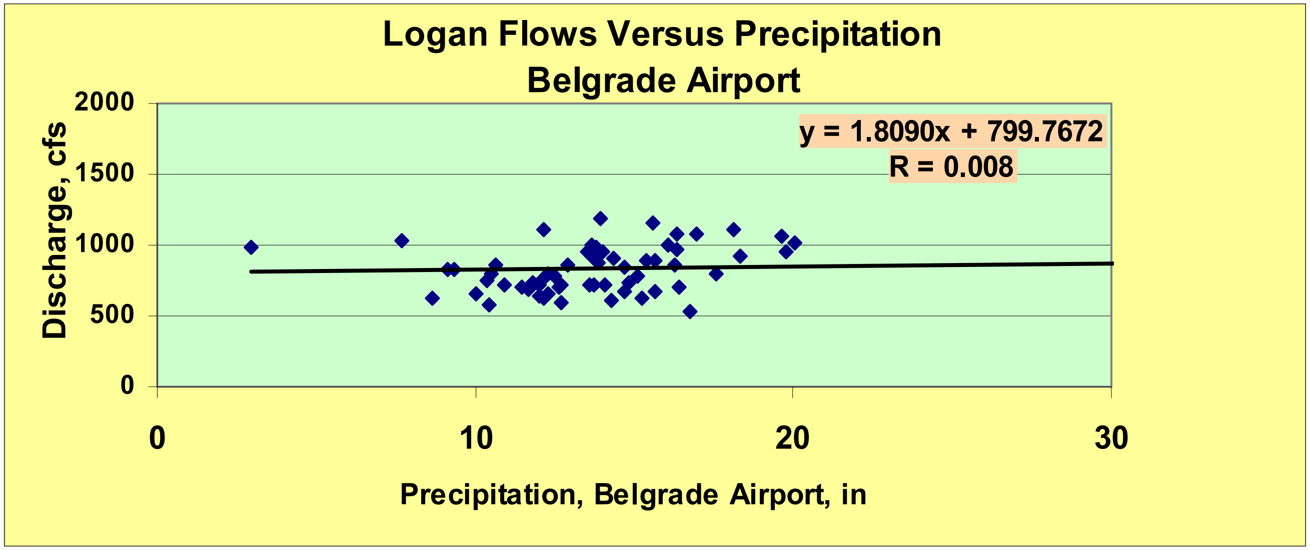


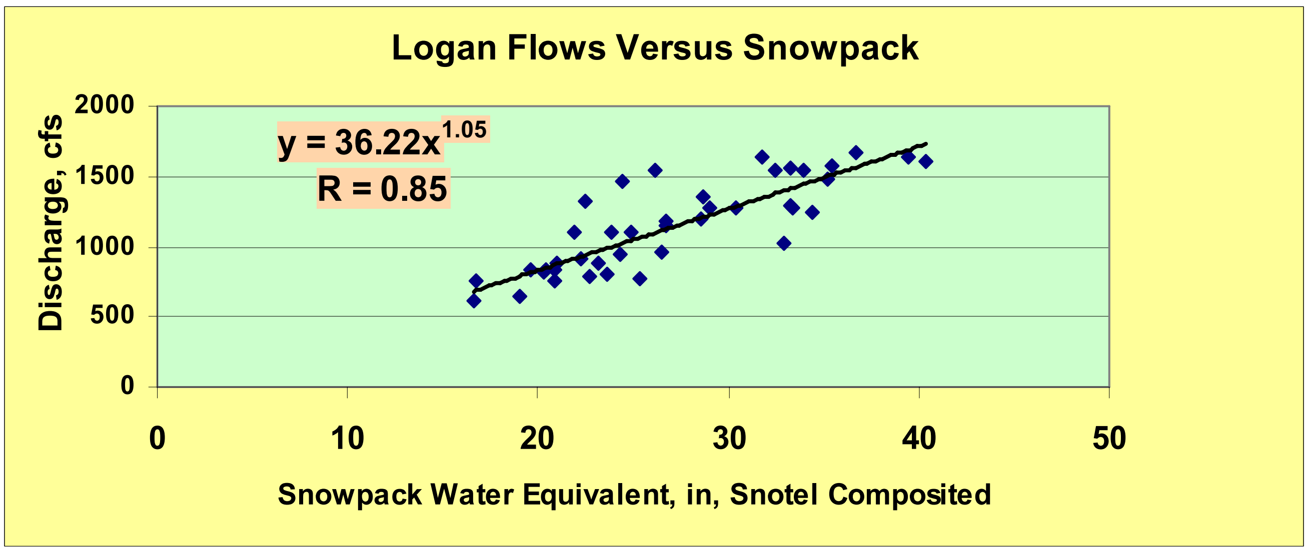
Date: 12/23/06 c:\leg\gal\rep\fig_12b For Doney Law Firm	NICKLIN EARTH & WATER, INC.	**Annual Precipitation and Cumulative Departure from Average MSU Experiment Station**	**Figure 12b**





Date: 12/23/06 c:\leg\gal\rep\fig_12c For Doney Law Firm	NICKLIN EARTH & WATER, INC.	**Annual Precipitation and Cumulative Departure from Average Belgrade Airport**	**Figure 12c**

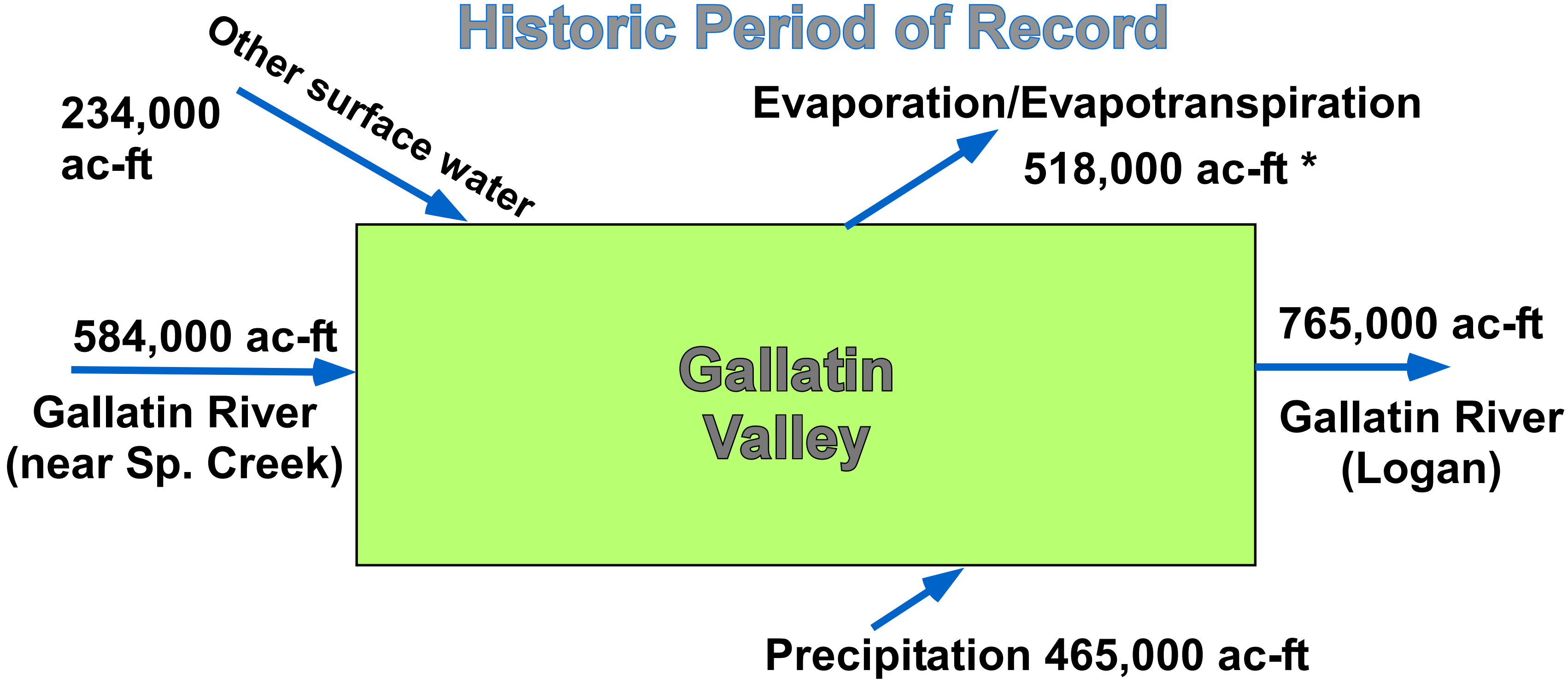




Note that this plot demonstrates that streamflow are mainly correlated to mountain snowpack and not to precipitation in the Gallatin Valley. Note that streamflow in the valley is similarly poorly correlated to precipitation at MSU and at MSU Experiment Station.

Date: 12/23/06 c:\leg\gal\rep\fig_13 For Doney Law Firm	NICKLIN EARTH & WATER, INC.	**Comparison of Streamflow Snowpack vs Precipitation**	**Figure 13**

Average Water Year
Valley Floor Mass Balance
Historic Period of Record

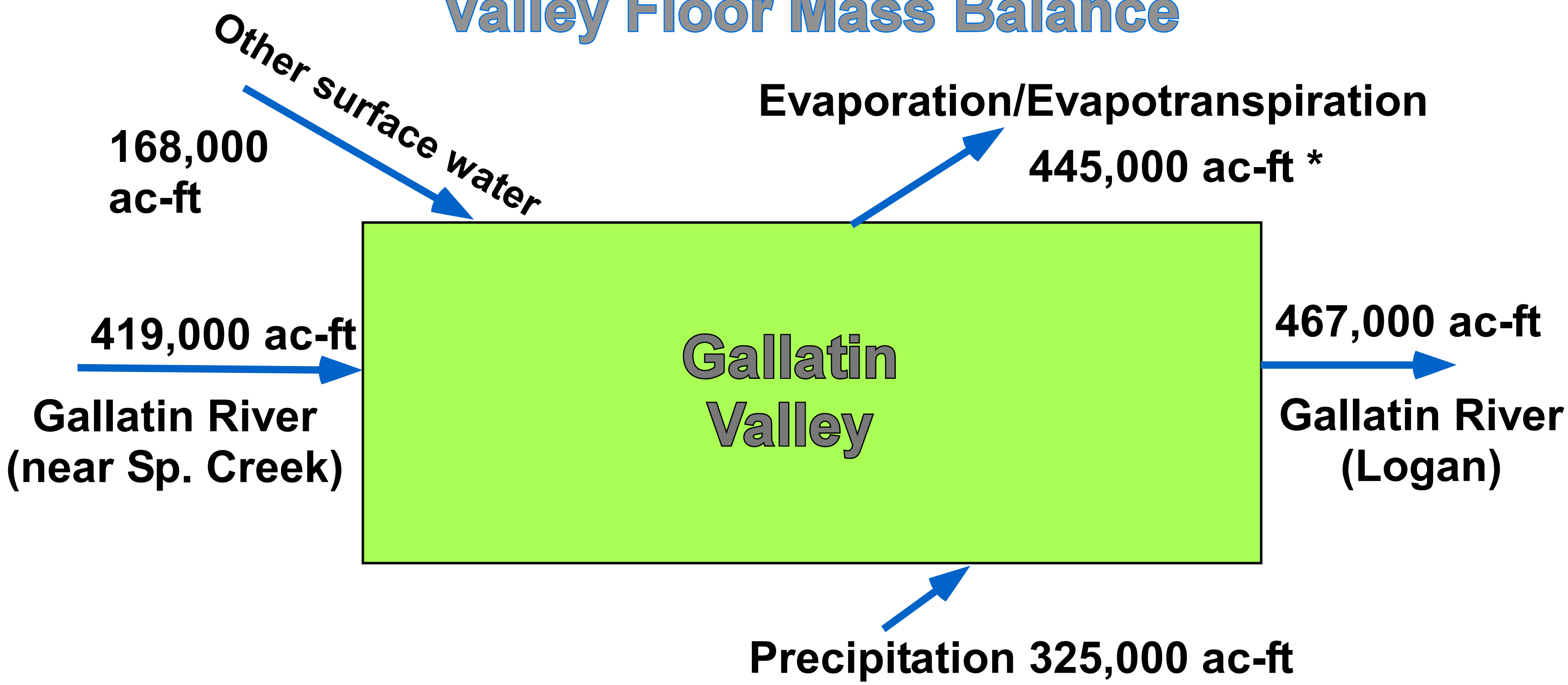


\# USGS 06052500 Gallatin River at Logan MT (period of record)
USGS 06043500 Gallatin River near Gallatin Gateway MT (period of record).
Other surface water defined on the basis of 1952 and 1953 interpretations by Hackett, et al (1960)
Precipitation based upon PRISM Interpretations. (see Figure 4).

* This value computed on the basis of the difference between other inputs and outputs. Storage changes over the period of record are assumed to equate to zero. Furthermore, ground-water contributions and losses at valley periphery are assumed to be small. This evaporation/evapotranspiration includes that due to natural factors and that associated with irrigation activity. This value equates to 1.50 feet or 18 inches per year valley wide.

Date: 01/02/07 c:\leg\gal\rep\fig_14 For Doney Law Firm	NICKLIN EARTH & WATER, INC.	**Water Balance Average Year Gallatin Valley**	**Figure 14**

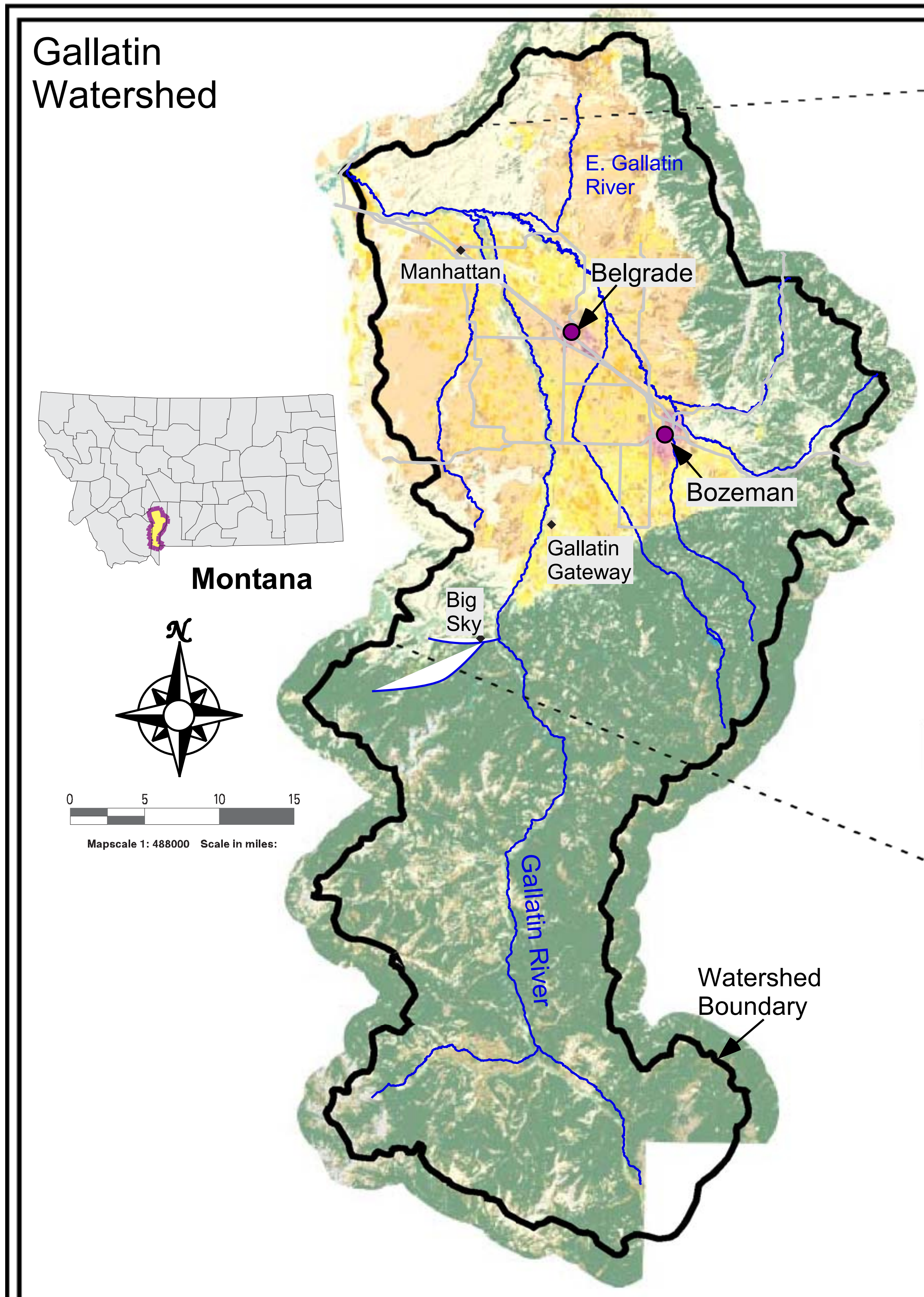
Dry Year (applies year 2001)
Valley Floor Mass Balance

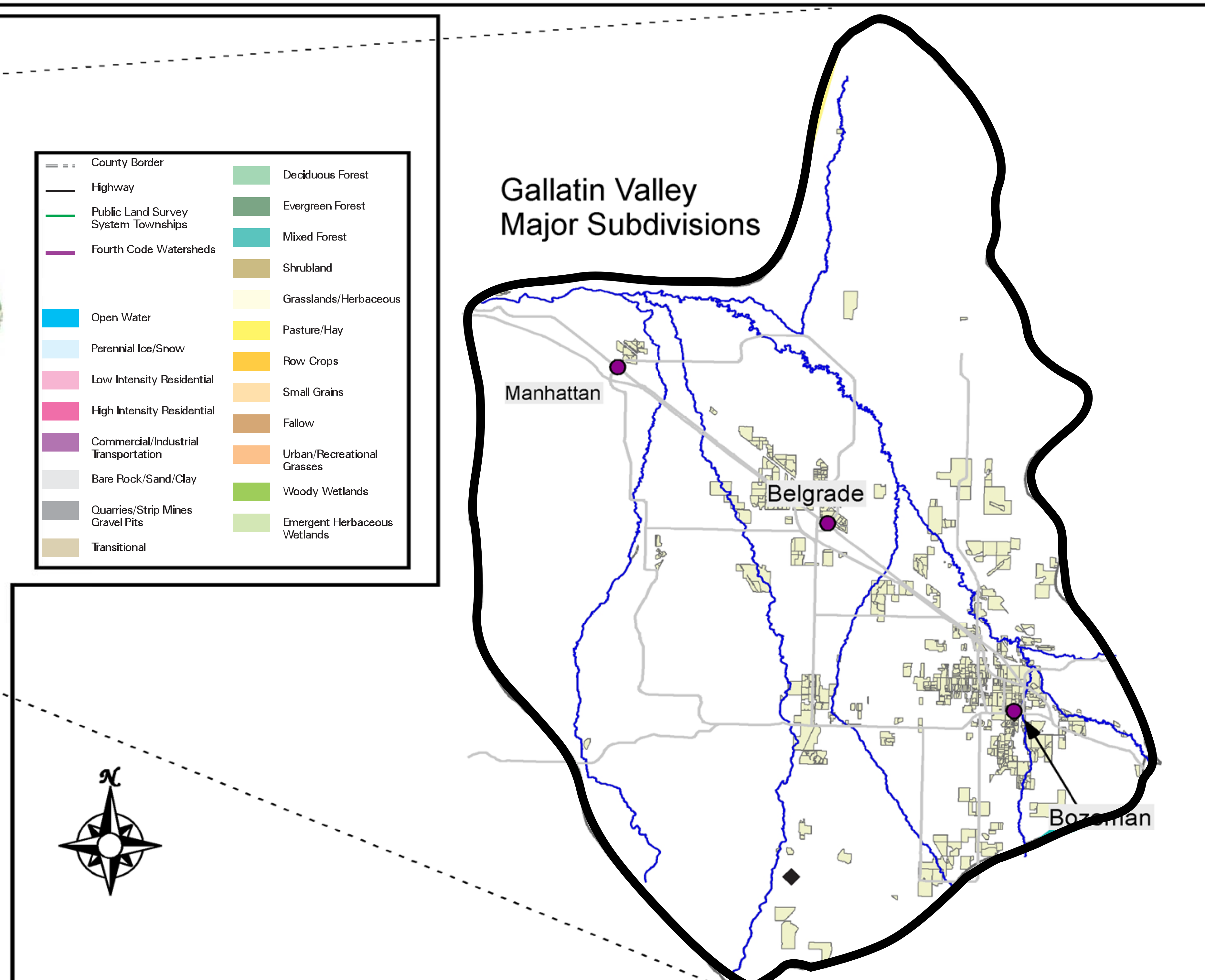


USGS 06052500 Gallatin River at Logan MT (period of record)
USGS 06043500 Gallatin River near Gallatin Gateway MT (period of record).
Other surface water defined on the basis of 1952 and 1953 interpretations by Hackett, et al (1960)
Precipitation based upon PRISM Interpretations and applying ratios of 2001 precipitation versus average years (Figure 4).

* This value computed on the basis of the difference between other inputs and outputs. Storage changes over the period of record are assumed to equate to zero. Furthermore, ground-water contributions and losses at valley periphery are assumed to be small. This evaporation/evapotranspiration includes that due to natural factors and that associated with irrigation activity. This value equates to 1.29 feet or 15.5 inches per year.

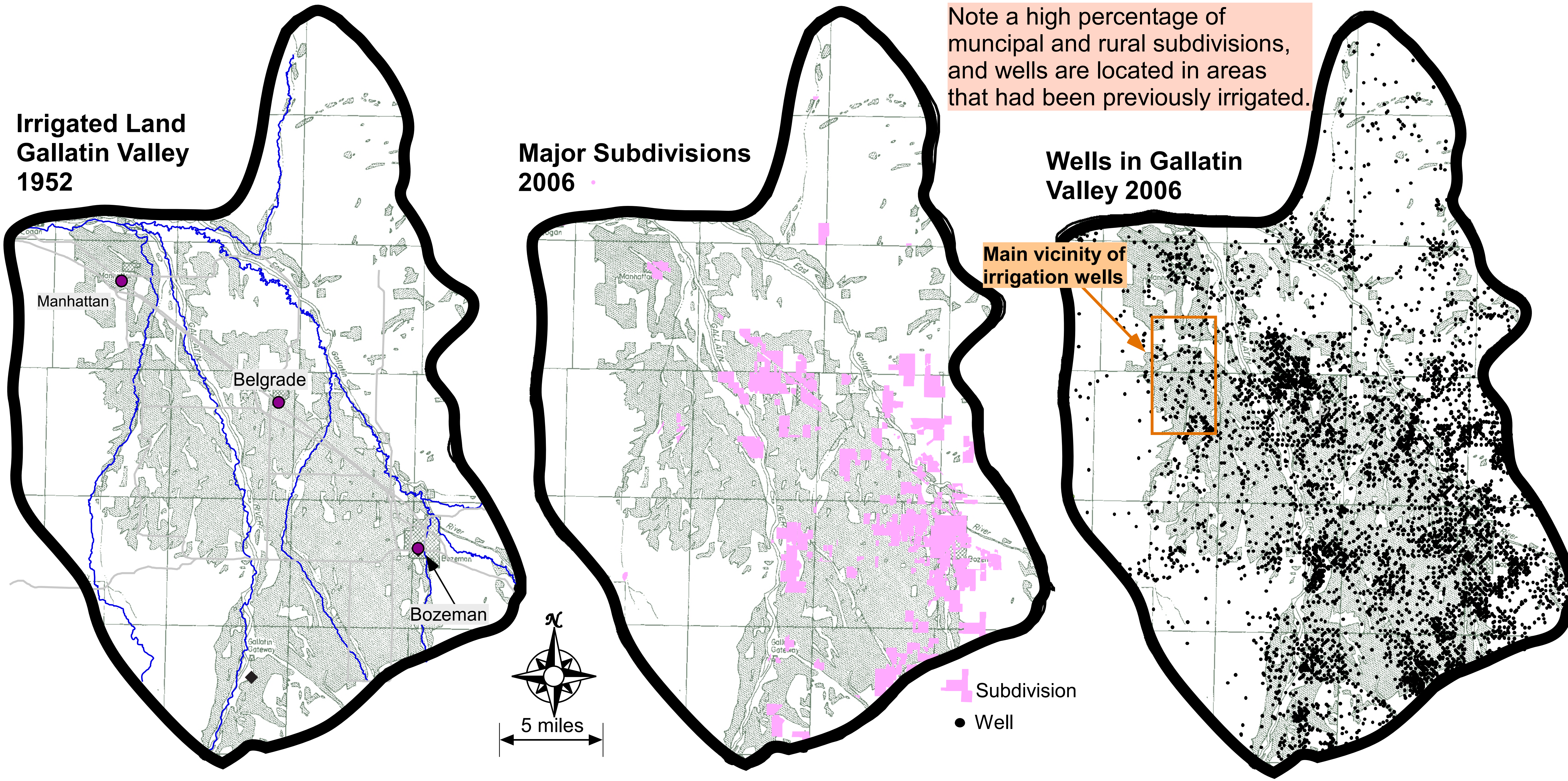
Date: 12/23/06 c:\leg\gal\rep\fig_15 For Doney Law Firm	NICKLIN EARTH & WATER, INC.	**Water Balance Dry Year Gallatin Valley**	**Figure 15**





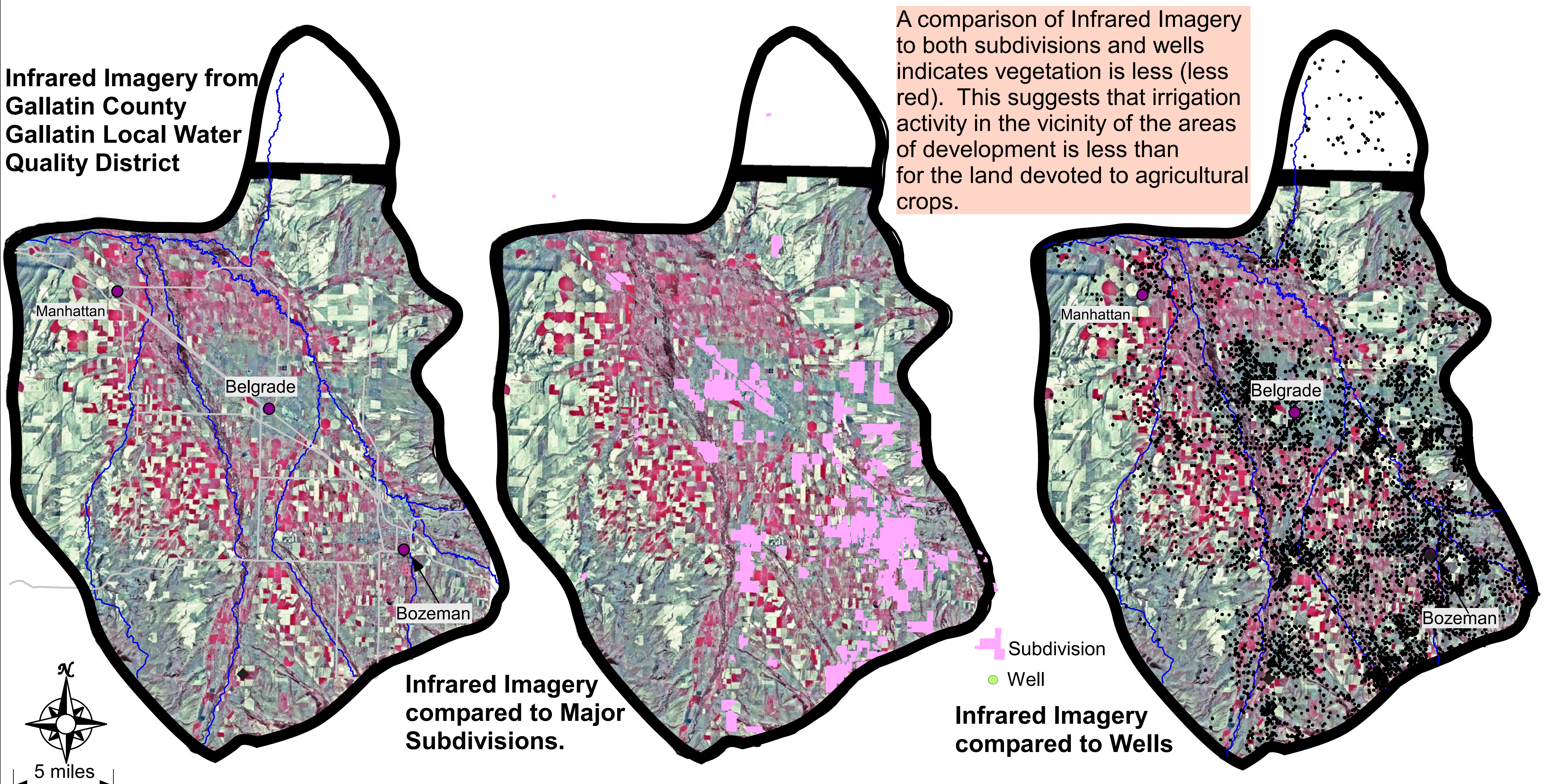
Presentation graphics adapted from plots retrieved for the Gallatin Watershed from Montana Natural Resource Information System (NRIS) - Montana State Library - Helena, MT.

Date: January 6, 2007 **File c:\leg\gal\Fig_16** **Issued for Doney Law Firm**	NICKLIN EARTH & WATER, INC.	**Land Use and Major Subdivisions** **Gallatin Watershed and Gallatin Valley**	**Figure 16**



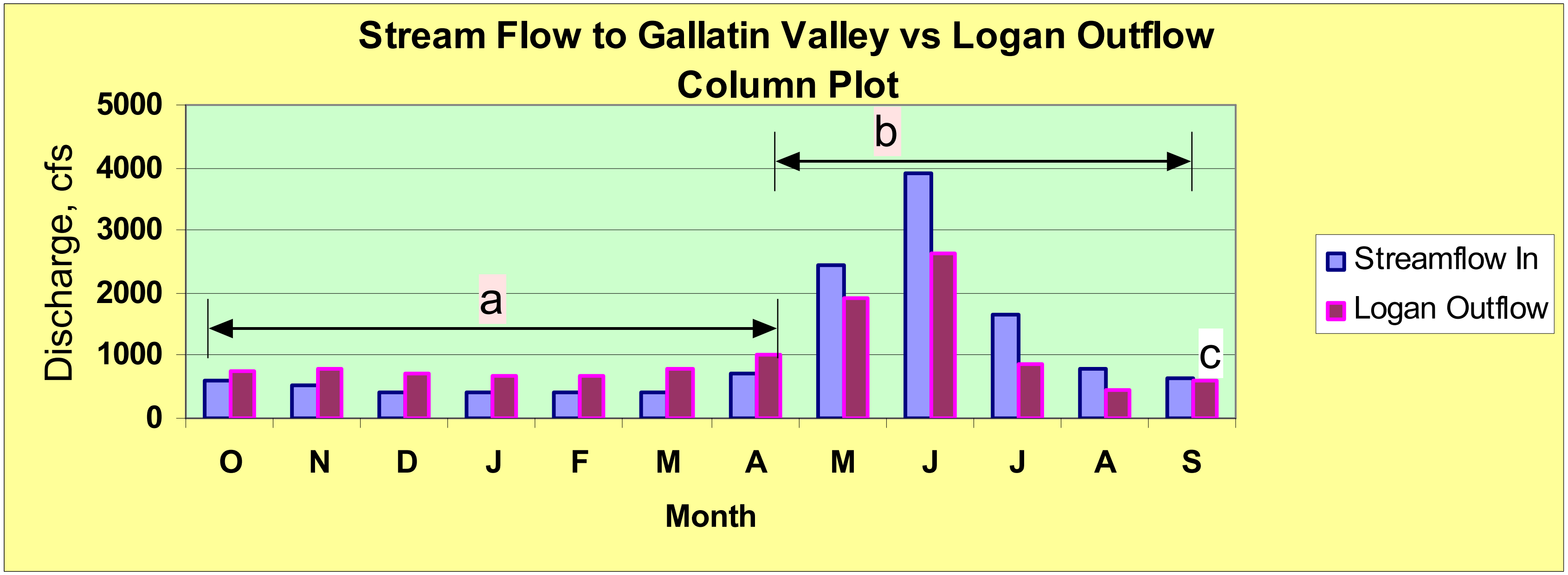
Subdivisions and Ground-water Information Center Data Obtained from for the Gallatin Watershed from Montana Natural Resource Information System (NRIS) Montana State Library - Helena, MT. Irrigated areas for 1952 were defined in Hackett, et al (1960). Hackett, et al adapted the map from the Montana State Engineer (1953).

Date: January 6, 2007 **File c:\leg\gal\Fig_17** **Issued for Doney Law Firm**	NICKLIN EARTH & WATER, INC.	**Land Use and Major Subdivisions** **Gallatin Watershed and Gallatin Valley**	**Figure 17**



Subdivisions and Ground-water Information Center Data Obtained from for the Gallatin Watershed from Montana Natural Resource Information System (NRIS) Montana State Library - Helena, MT. Irrigated areas for 1952 were defined in Hackett, et al (1960). Hackett, et al adapted the map from the Montana State Engineer (1953).

Date: January 6, 2007 **File c:\leg\gal\Fig_18** **Issued for Doney Law Firm**	NICKLIN EARTH & WATER, INC.	**Infrared Imagery Compared To Major Subdivisions and Wells Gallatin Valley**	**Figure 18**



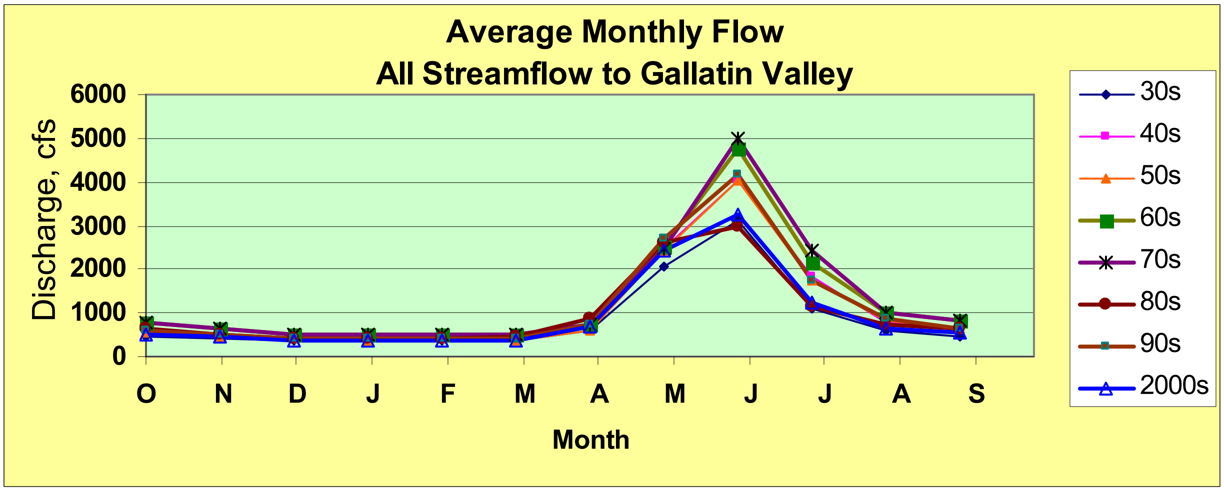
a - Outflows at Logan exceeds surface water flow entering the valley.

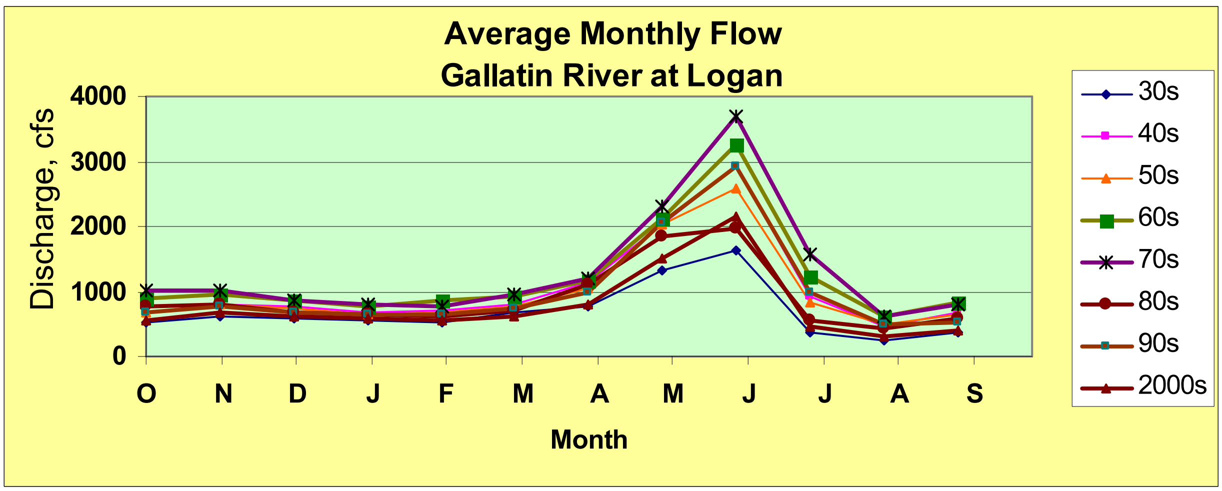
b - Inflows to Valley exceeds surface water exiting the valley. This represents a period time of significant surface water diversions.

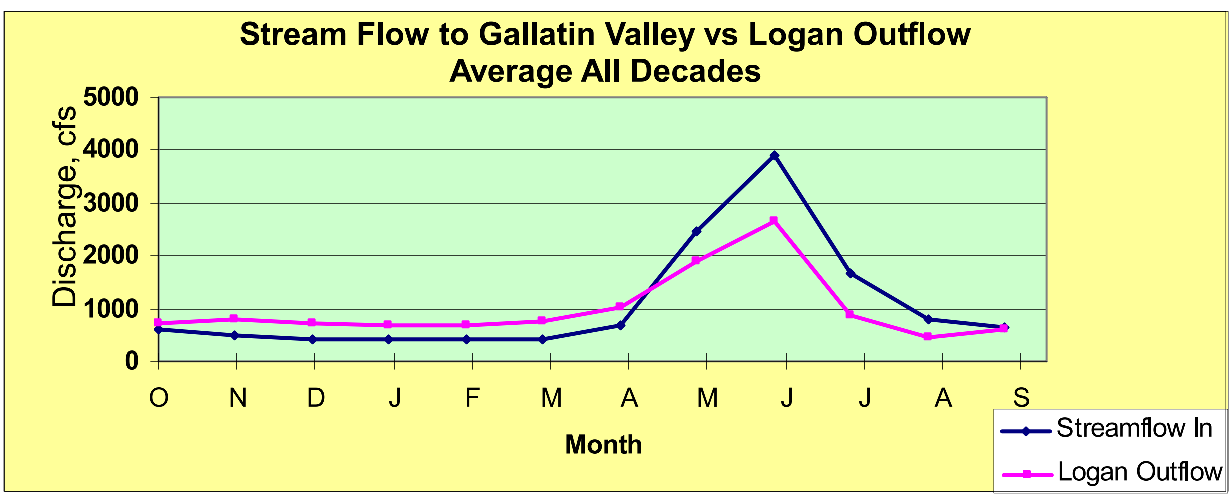
c - Flows begin to increase at Logan following the cessation of the irrigation season (less surface water is being diverted for irrigation).

Note: The estimated streamflow to the Gallatin Valley is estimated by prorating the Gallatin River flow near Gallatin Gateway by a factor of 1.4. This ratio is based upon the relative contributions of other streams into the valley defined in Hackett, et al (1960).

Date: 01/10/06 c:\leg\gal\rep\fig_19 For Doney Law Firm	NICKLIN EARTH & WATER, INC.	**Evaluation of Streamflow Entering Valley vs Streamflow Leaving Valley at Logan**	**Figure 19**

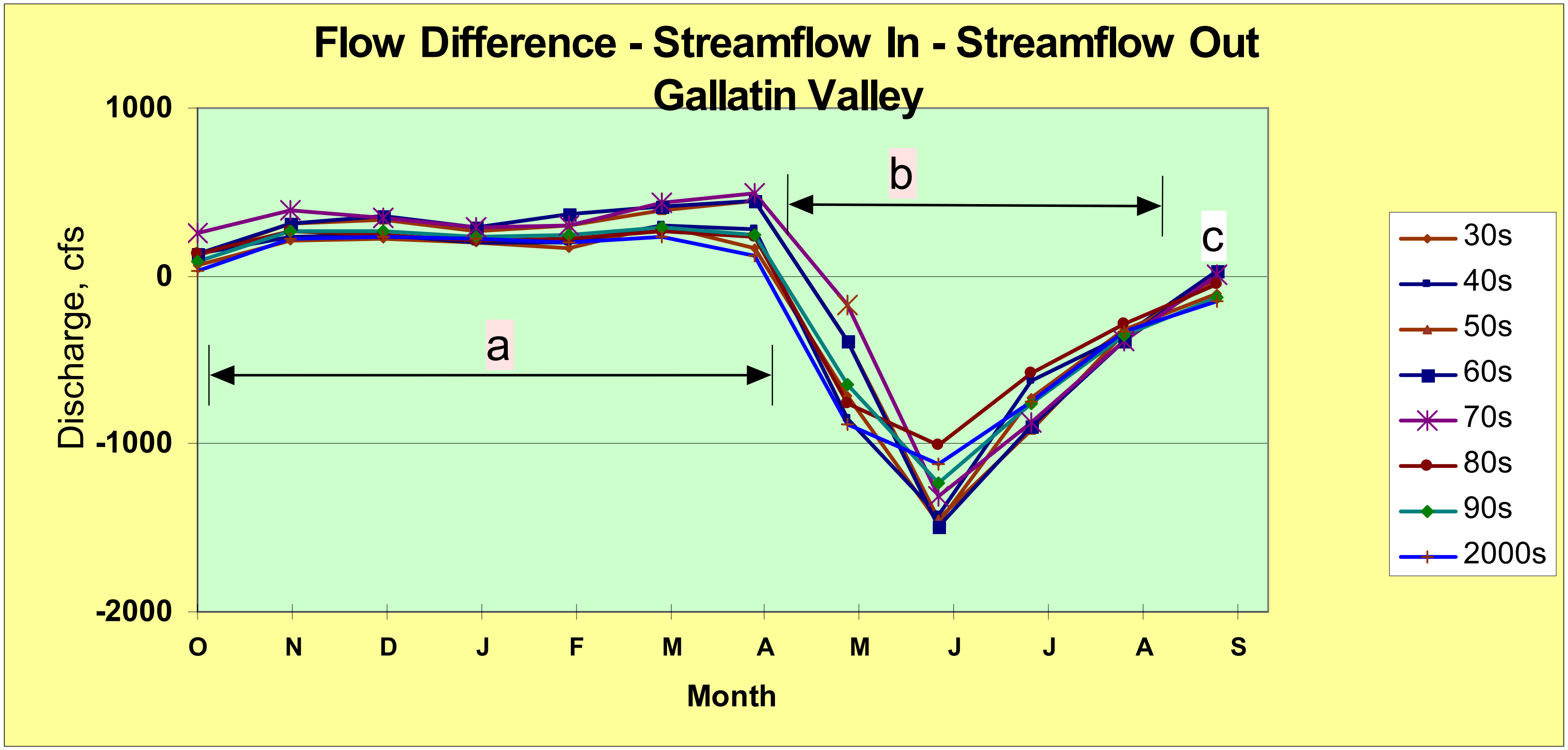






Note: The estimated streamflow to the Gallatin Valley (upper plot) is estimated by prorating the Gallatin River flow near Gallatin Gateway by a factor of 1.4. This ratio is based upon the relative contributions of other streams into the valley defined in Hackett, et al (1960).

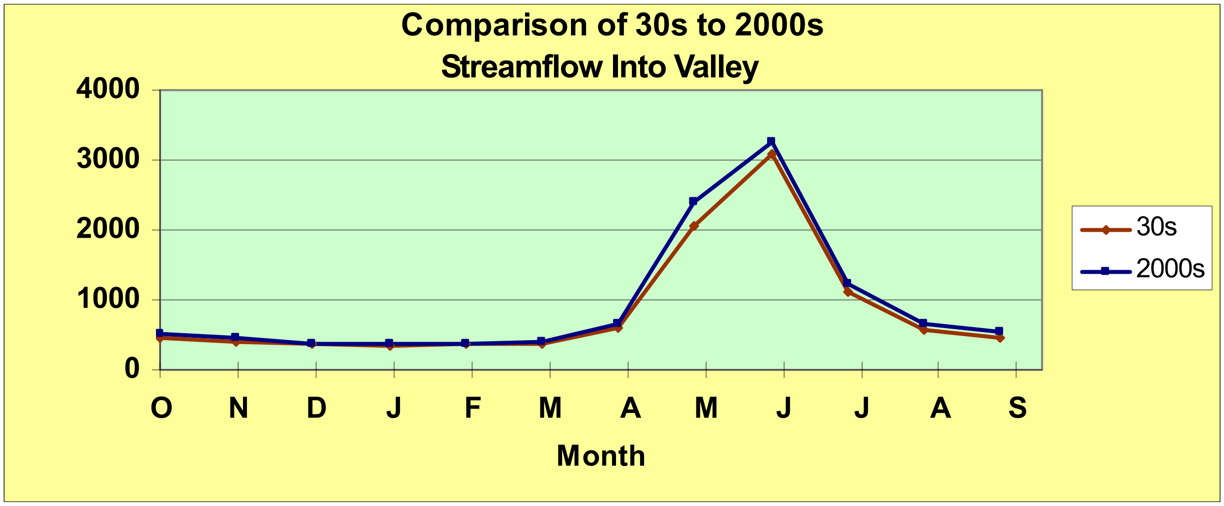
Date: 12/23/06 c:\leg\gal\rep\fig_20 For Doney Law Firm	NICKLIN EARTH & WATER, INC.	Plots of Monthly Average Flows Gallatin River near Gateway and at Logan	Figure 20

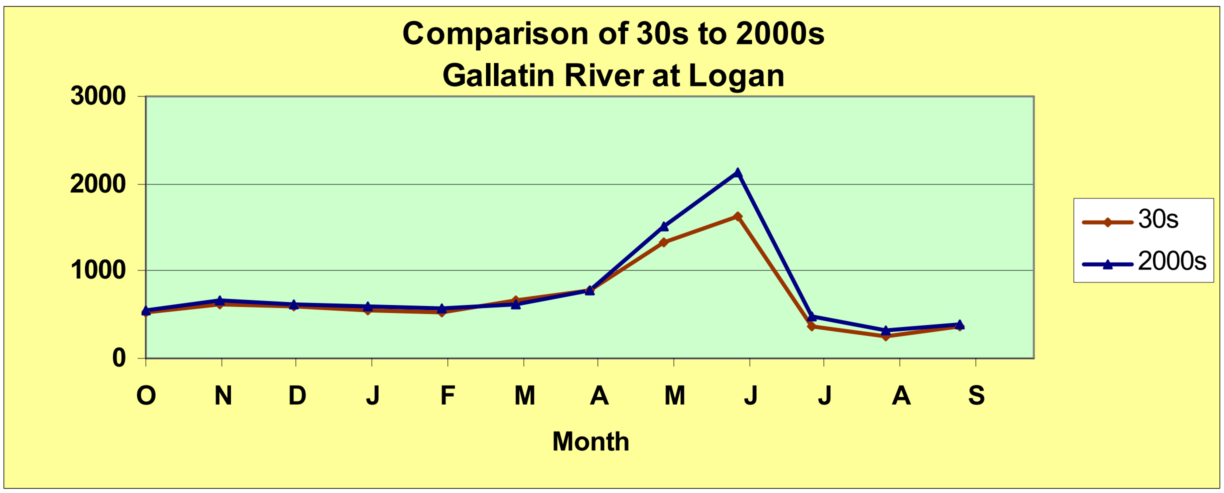


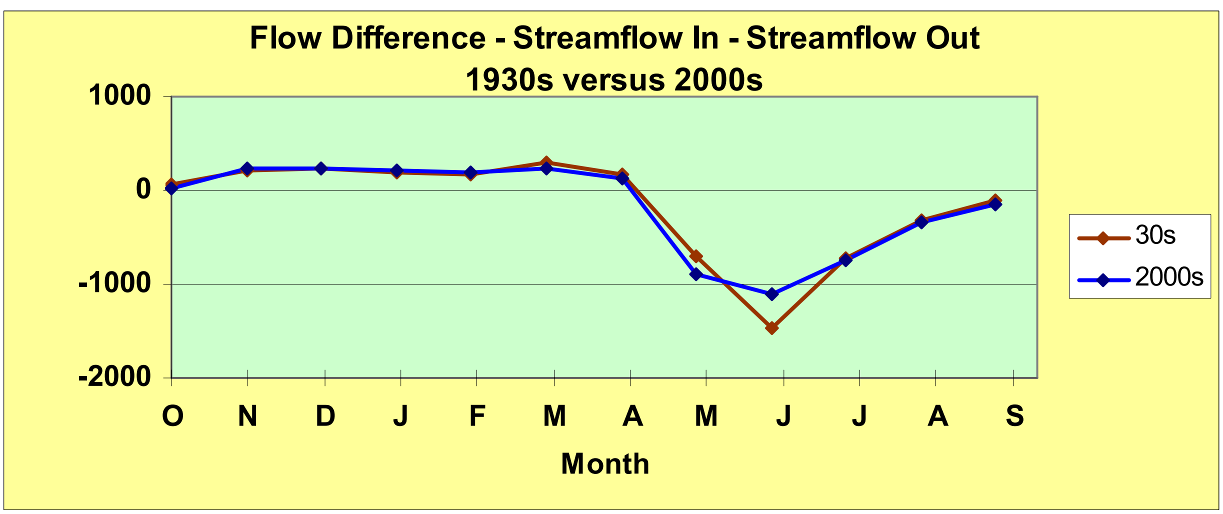
These plots represent the amount of change in stream flow that is observed on a monthly basis through the period of record. Negative values imply stream flow exiting the valley is less than that entering the valley. When flows are negative, this reduction is mainly from agricultural surface water diversions. When values are positive, this represents the relative ground-water contribution to surface water flow exiting the valley. Note that the plots are very similar from decade to decade. The relative magnitude of this difference is dependent upon the relative magnitude of flow entering the valley and upon how surface water is managed by irrigators.

See Figure 19 for letter label designations.

Date: 12/23/06 c:\leg\gal\rep\fig_21 For Doney Law Firm	NICKLIN EARTH & WATER, INC.	**Comparison of Inflow vs Outflow Difference Eight Decades - Gallatin Valley**	**Figure 21**

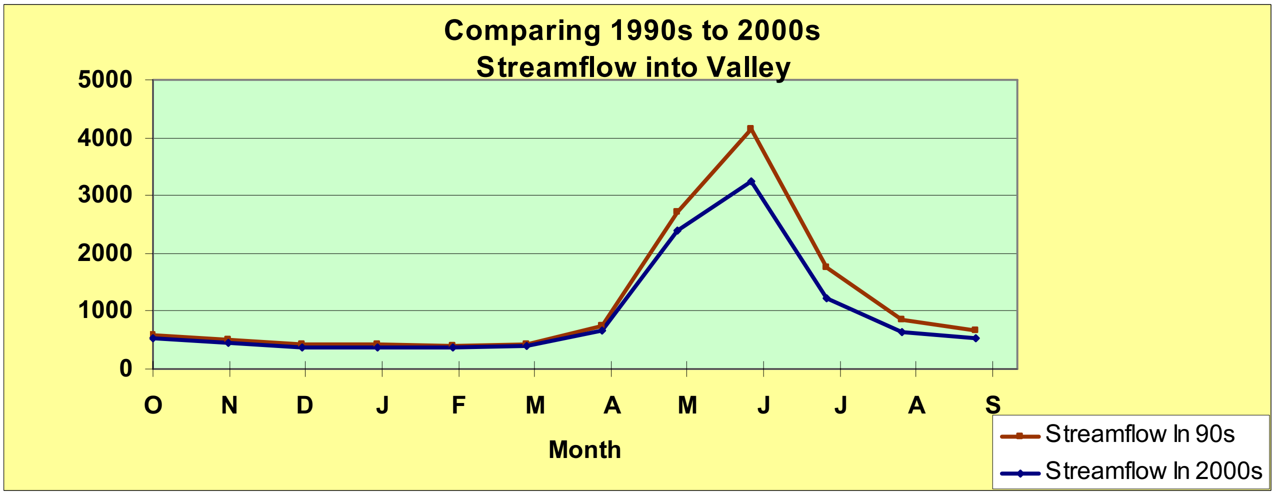


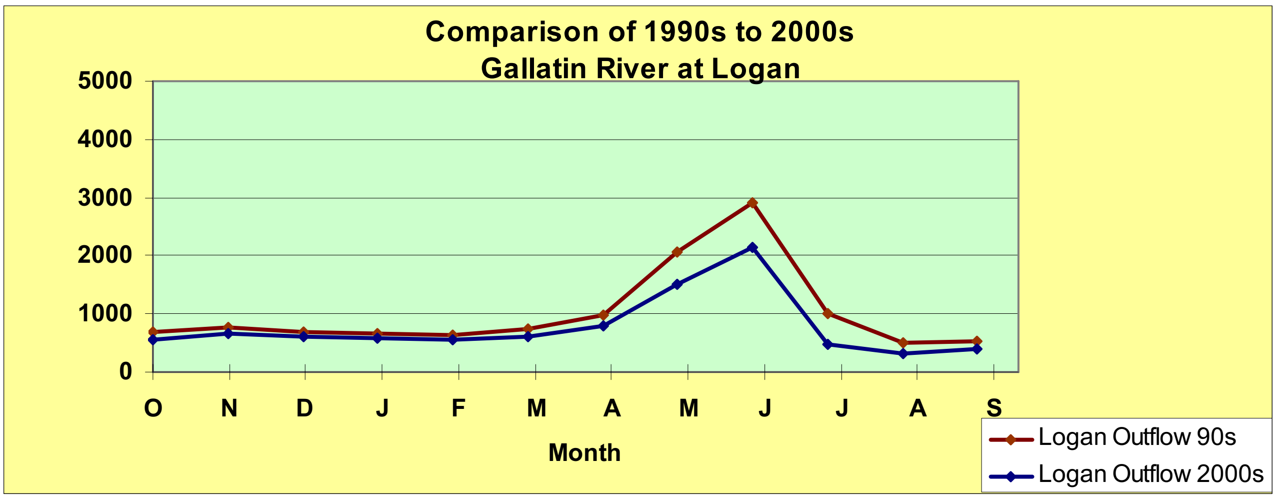


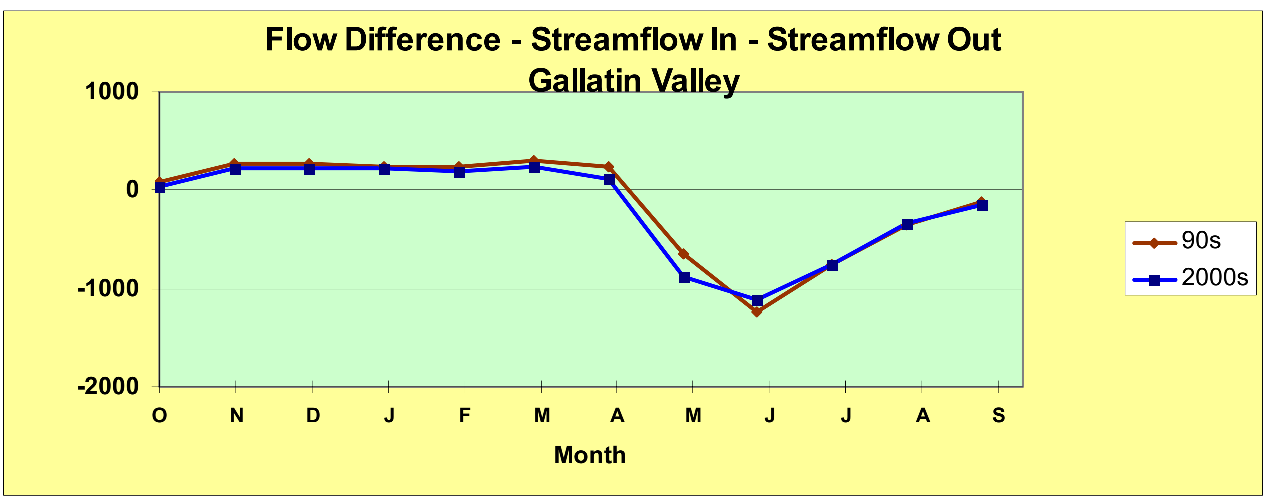


These plots compare the 1930s to the 2000s two different periods of drought. When flow differences are compared during the irrigation months from July through August, and then during the fall and winter (from October through February), the net differences are nearly the same. This suggests that net consumptive uses in the 1930s are very similar to those that occurred in the 2000s.

Date: 01/06/07 c:\leg\gal\rep\fig_22 For Doney Law Firm	NICKLIN EARTH & WATER, INC.	**Comparisons** **Inflow and Outflow** **1930s versus 2000s**	Figure 22



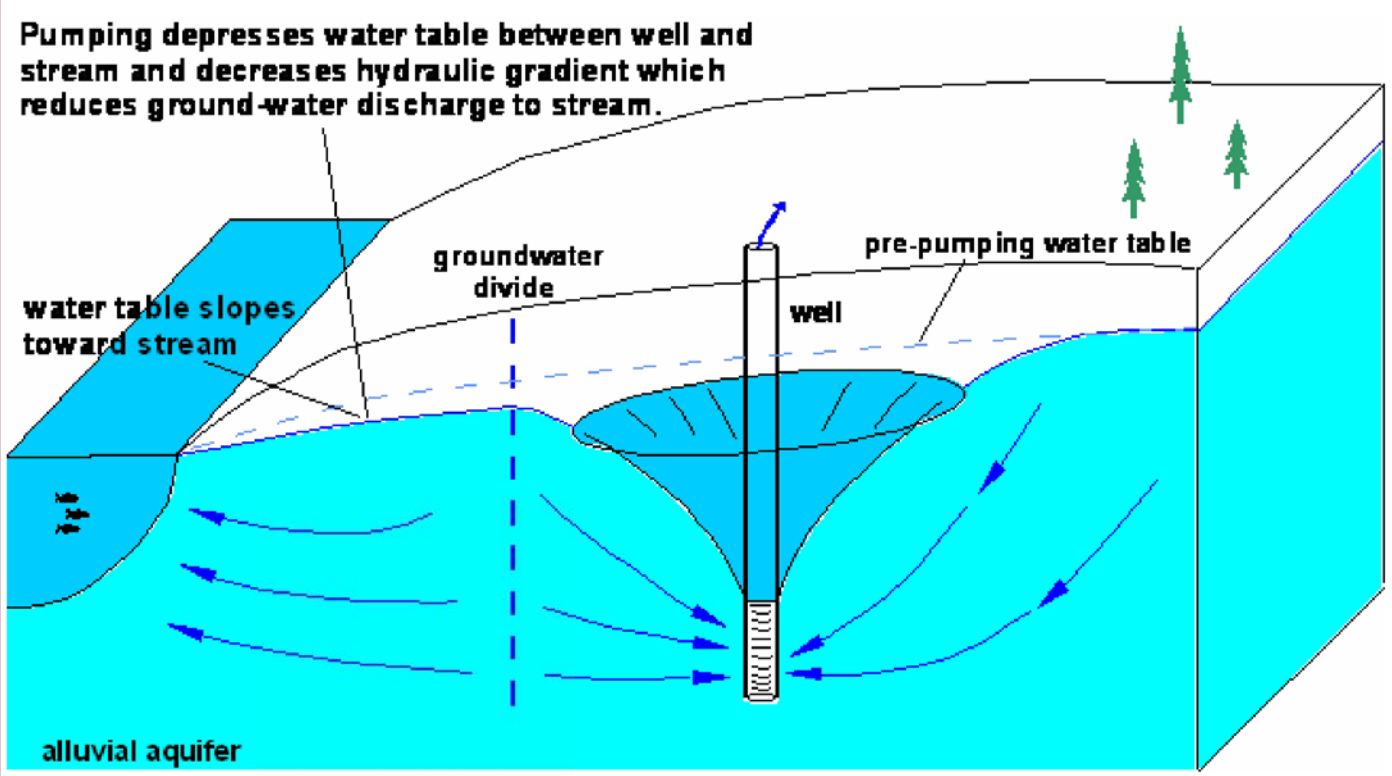




These plots compare the 1990s to the 2000s. Both inflow to and outflow from the valley were higher in the 1990s compared to the 2000s. Yet, when flow differences are compared during the irrigation months from July through August, the net impacts of irrigation have affected the Gallatin River flows the same way for these two decades.

Date: 01/06/07 c:\leg\gal\rep\fig_23 For Doney Law Firm	NICKLIN EARTH & WATER, INC.	**Comparisons Inflow and Outflow 1990s versus 2000s**	Figure 23

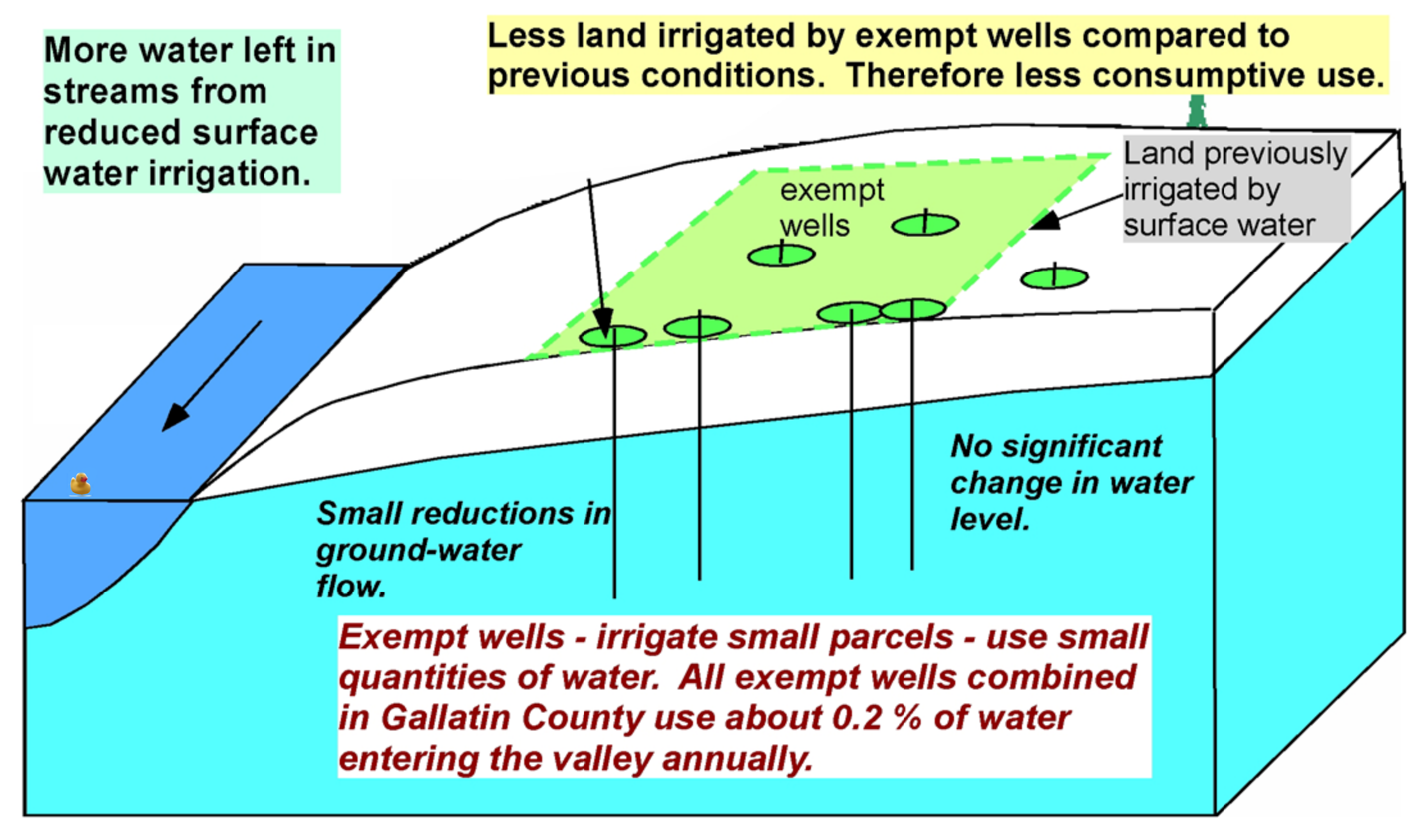
DNRC's Slide



Groundwater intercepted by well would have eventually discharged to stream; <u>prestream capture of tributary groundwater</u>

NE&W Comment:

Generally, exempt wells, even multiple exempt wells clustered in a subdivision, do not create the gross cones of depression that are shown above, simply because exempt domestic wells use negligible amounts of groundwater. The typical average daily flow rate for an exempt well is 0.6 gpm. Most streams are in alluvial valleys that possess aquifers of relatively high transmissivity (high water-bearing capacity). For a cone of depression to exist of the size portrayed in DNRC's slide, a well would have to have an average daily flow rate of well over a thousand gallons per minute (gpm).

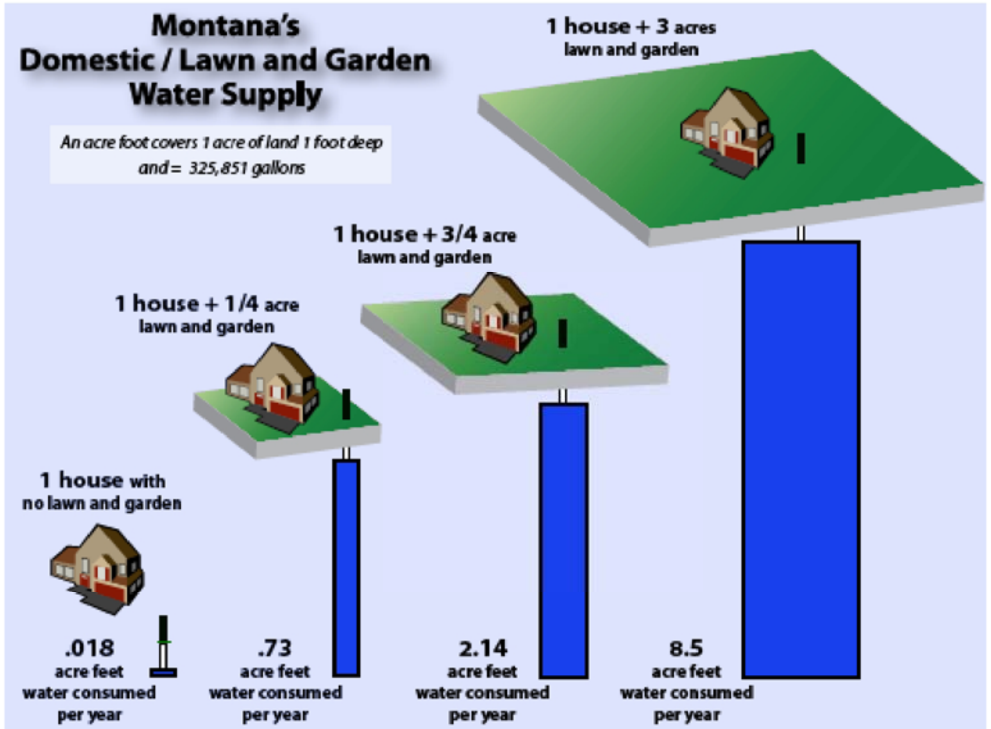


<u>Another scenario not disclosed by DNRC:</u>

This perspective is more representative what is actually being observed in the Gallatin Valley based upon evaluations of infrared photography, and data collected by the U.S. Geological Survey and the Montana Bureau of Mines and Geology. This figure illustrates the process of addition (wells) and subtraction (reduced consumption from less surface water irrigation). If less land is irrigated by surface water, there will be more surface water available to others.

Before drawing conclusions as to the overall net outcome of exempt wells on surface water flows, evaluations <u>(addition and subtraction)</u> on a watershed or sub-watershed scale should be conducted to determine the overall net change in consumptive use which may either increase, decrease or remain about the same.

Date: January 6, 2007 File c:\leg\doney\gal\Fig_24 Issued for Doney Law Firm	NICKLIN EARTH & WATER, INC.	**Evaluation of DNRC Power Point Slide Compared to Conditions for Gallatin Valley**	**Figure 24**



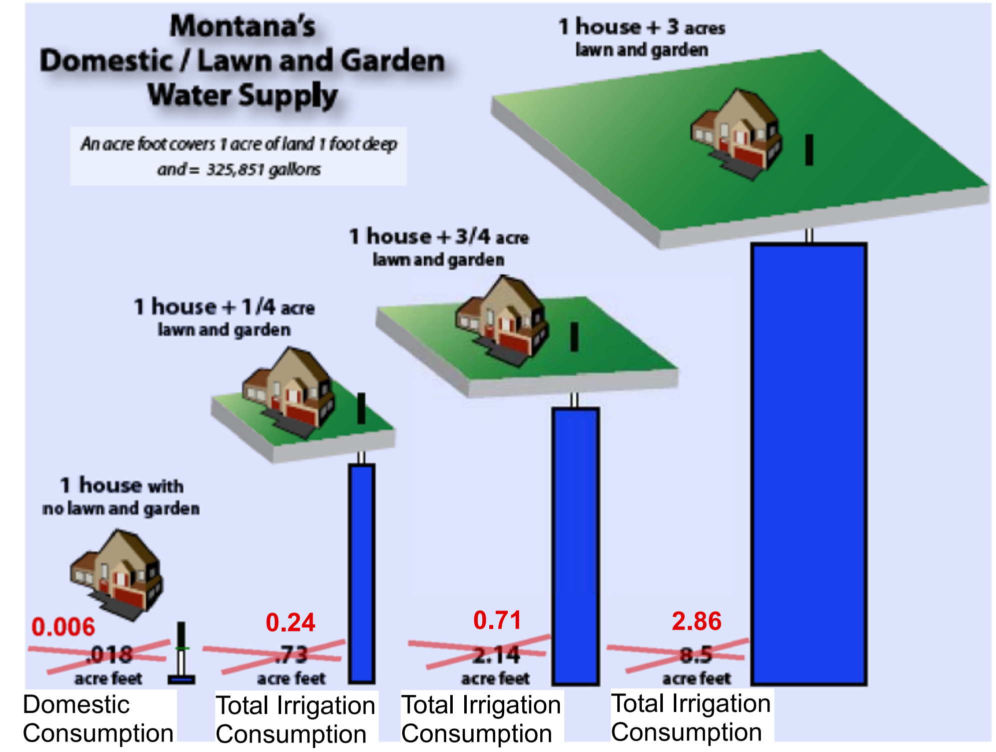
<u>*This DNRC slide is not representative for lawn and garden consumption in Montana*</u>. It also warrants clarification. The following are NE&W's comments:

1. Portions of lawn and garden plant consumption (Et) are supplied by nature via precipitation (effective precipitation). In other words, this happens either with or without irrigation.

2. The remainder of the water demand for plant consumption (Et) is supplied by irrigation on irrigated lawns/gardens.

3. The actual irrigation (consumptive use) is much smaller than what is computed above. Excess water that is applied recharges the underlying ground water.

4. It is <u>*highly unlikely*</u> that there is anywhere in Montana where lawns and gardens consume 2.91 feet (35 inches) which is required for the consumption numbers shown above. Refer to the bottom row of Table 1 for an example.



<u>Using more recent information and applying it to Gallatin Valley:</u>

1. Typical domestic consumption is about 2 % of household demand (see Attachment C). This equates to about 0.006 acre-ft per house per year.

2. Effective precipitation (see Table 1) is 8.85 inches or 0.18 acre-ft for a quarter acre of irrigated garden and land *[nature's contribution, i.e., this happens with or without irrigation]*. See Dr. Westesen analysis, Attach ment A for effective precipitation evaluation.

3. Net consumption of irrigation water is 0.24 acre-ft per quarter acre of irrigated lawn and garden. Combining nature (0.24 acre-ft) and the irrigation water yields a total consumption Et) of 0.42 acre-ft for a quarter acre of irrigation.

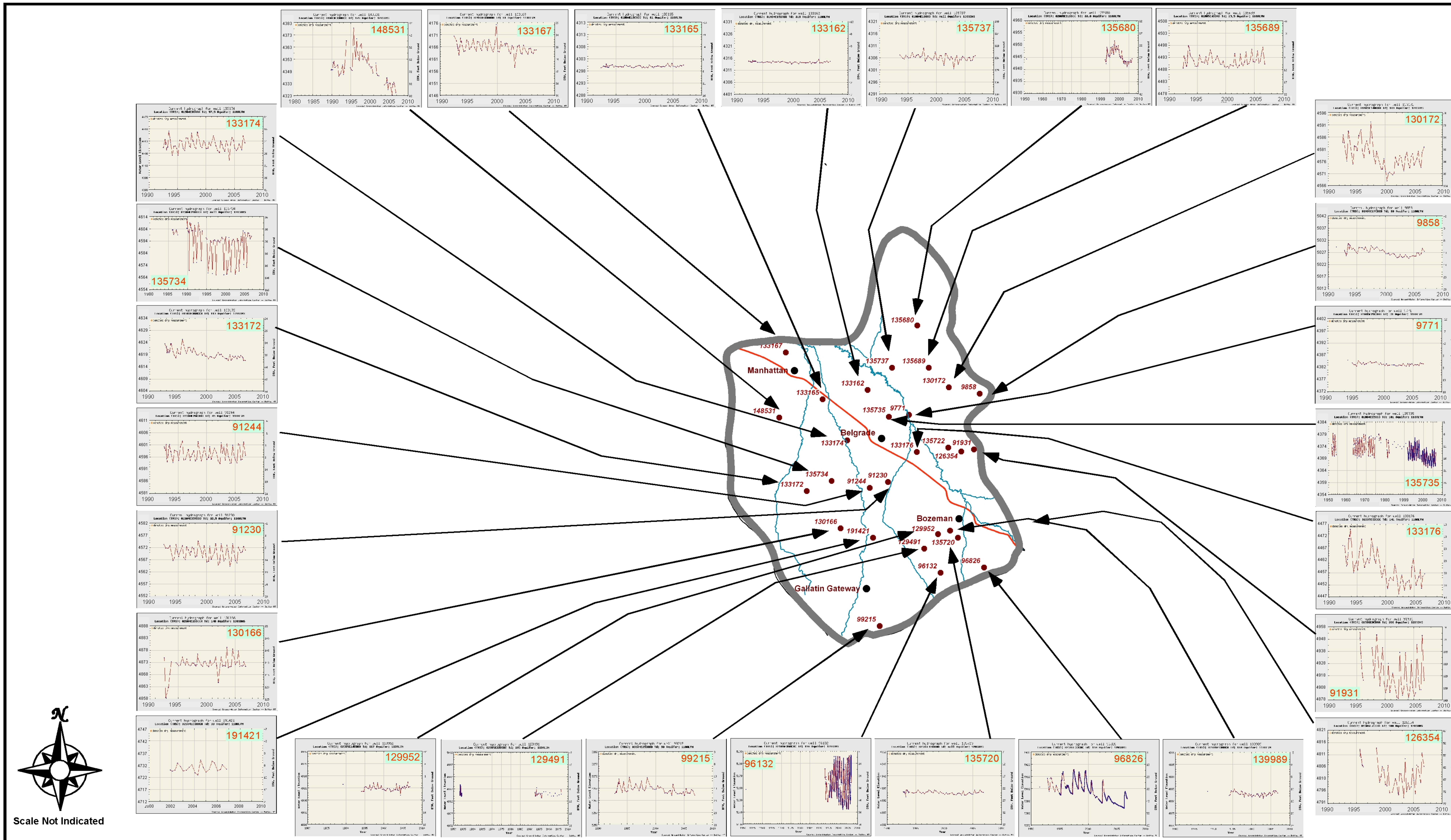
4. <u>There is another factor</u> that further reduces the impacts of lawn/garden irri gation which are not included in the above assessment. This is impervious surfaces (roofs and paved driveways) that eliminate plant Et where they are present.

Date: January 6, 2007
File c:\leg\doney\gal\Fig_25
Issued for Doney Law Firm

NICKLIN EARTH & WATER, INC.

Evaluation of DNRC Power Point Slide
Consumptive Use Lawn and Garden

Figure 25



Note: All plots obtained directly from the Montana Bureau of Mines and Geology. The vertical (feet) and horizontal axes (year) were visually enhanced for readability by NE&W. Original plots are in Attachment D.

Date: January 6, 2007 **File c:\leg\doney\gal\Plate 1** **Issued for Doney Law Firm**	NICKLIN EARTH & WATER, INC.	**Hydrographs of Gallatin Valley Wells** **MBMG Statewide Monitoring Network**	**Plate 1**

Attachment A

Evapotranspiration Evaluation - Gallatin Valley
by
Dr. Gerald Westesen, Professor Emeritus, Montana State University

Gallatin Valley Evapotranspiration Analysis

Prepared for Michael Nicklin, PhD, PE, Nicklin Earth & Water Inc.

By

Gerald L. Westesen, PhD, Professor Emeritus, Montana State University

Introduction

The evapotranspiration (ET) component is part of and partial input to a water mass balance study for a portion of the Gallatin Valley. The chief source of information for this ET study is the Montana Irrigation Guide (MIG) prepared by the SCS. Additional sources include studies done in Colorado, Utah, Idaho, and California of various crops and phreatophytes.

The information of ET in the MIG is based of a document commonly referred to as TR21 which outlines a procedure based on the Blaney-Criddle formula. This formula incorporates daylight hours, temperature, and crop information. It is simple but has stood the test of time and is recognized as being correct and appropriate for Montana.

Analysis

Two locations were evaluated as part of this study and they were Montana State University (MSU) and the Belgrade airport. Information concerning MSU and the Belgrade airport is found in the MIG.

TR21 suggests that more correct results will be obtained when a 3% correction for each 1000' above 3000' is added to the ET numbers listed. This was done for the crops analyzed. In addition the irrigation requirement is given for normal and dry years. Note that the ET is the same in normal and dry years.

The amount of irrigation water needed to meet crop ET requirements is modified by the amount of effective rainfall. Effective rainfall is the portion of the normal rainfall that is utilized by the crop. Effective rainfall percentage is greater in dry years. The MIG uses an effective rainfall percentage of 50% for normal years and 80% for dry years.

Until seasonal ET requirements are met for non irrigated vegetation a high percentage of rainfall is effective, but some still evaporates and some enters the groundwater below the root zone. An effective rainfall amount of about 80% for non irrigated vegetation is an accepted value.

The irrigated crops considered in this study are alfalfa, spring grain, pasture, and turf.

In addition a non-irrigated composite grassland vegetation is examined as well as phreatophytes such as willows, and cottonwoods.

From the MIG and modified for elevation the appropriate ET values for the crops considered at the geographic stations during a normal and dry year are:

MSU	irrigated alfalfa	21.1"	with elevation correction 23.1"
Belgrade Airport	irrigated alfalfa	20.8"	with elevation correction 21.8"
MSU	irrigated Spring grain	16.2"	with elevation correction 17.1"
Belgrade Airport	irrigated Spring grain	16.0"	with elevation correction 16.7"

Comment: by examination the ET at the two sites is very close to the same. Is it worth including both, or should the values at the two sites be averaged? Belgrade would probably best represent the Gallatin Valley.

Calculation of normal precipitation

Comment: The MIG uses 50% and 80% as the effective precipitation for normal and dry years. Therefore the effective precipitation value for normal years can be doubled to give the normal rainfall at the station during the growing season. This value does not include non growing season precipitation. The following are taken from the alfalfa analysis.

MSU	May-September effective ppt	6.65"	rainfall	13.3"
Belgrade Airport	May-September effective ppt	4.43"	rainfall	8.9"

As a check on the 50 and 80% values for effective precipitation a more detailed analysis was done following the procedure given in TR21. This analysis did not take into account wet or dry years. The result was an effective precipitation value of 65%. The values of 50, 65, and 80 percent are all "in the ballpark". This is not an exact science.

Estimation of grassy non-crop vegetation ET

The closest "crops" to grassy native vegetation for listings in the MIG is probably turf or pasture grass. Interestingly these two crops both have identical ET of 20.28". This value is substantially higher than the normal rainfall during the growing season. *Using the previously discussed value of 80% of the rainfall being effective the amount of rainfall would be .8 x 13.3 =10.6" for the MSU station and .8 x 8.9 =7.1" for the Belgrade station*. Both of these values are substantially less than the possible ET. The conclusion is that the water use (ET) by grassy non-crop vegetation is limited by the available water and would never exceed the irrigated ET of turf and pasture grass.

Estimation of Phreatophyte ET

The MIG has no information about phreatophytes. The best analysis found was a study done by S. E. Rantz for the California Department of Water Resources. The results are presented graphically. The depth to the water table is graphed versus the crop coefficient K in the Blaney Criddle formula. The K for alfalfa is nominally one. The values for cottonwoods and willows are: 8-.95, 7-1.0, 6-1.1, 5-1.2, 4-1.4, 3-1.5, 2-1.7, 1-2.0. Essentially what Rantz is indicating under high water table conditions the ET of cottonwoods and willows can be twice the ET of alfalfa. This seems intuitively correct and when combined with the phreatophyte acreage developed by the U.S. Geological Survey (Hackett, et al) yields a major water use component.

Further Questions and Comments

Is there a difference in ET for crops under flood or sprinkler irrigation?

No, the ET is the same. The irrigation water requirement will probably be different because of differences in system efficiency. Sophisticated and well operated furrow and border systems can be more efficient than sprinklers. This condition rarely occurs in Montana.

What about evaporation loss under sprinklers?

There is evaporation loss, but the wetting of the crop reduces its ET. For well established crops covering the ground surface it is a standoff. Evaporation loss does occur when sprinkling bare ground.

ET analysis for Gallatin Valley

1. Agricultural assessment for 3 areas, MSU, Belgrade, Camp Creek Hills

a.) Montana State University (all based on normal year)

irrigated alfalfa (MT Irrigation Guide)

ET 21.91"
effective ppt 6.65
assuming 60% rainfall effective
seasonal rainfall 6.65/.6 = 11.1"

ET corrected for elevation
$1 + \frac{4856 - 3000}{1000} \times .03 = 1.856 \times .03 = .0557$

b)

$21.91 \times 1.0557 = 23.1"$

Belgrade Airport (normal year)

irrigated alfalfa (MT Irrigation Guide

ET 20.80
effective rainfall 4.43
assuming 60% rainfall effective
seasonal rainfall = 7.38

ET corrected for elevation
$1 + \frac{4451 - 3000}{1000} \times .03 = 1.0435$
ET = 20.80 x 1.0435 = 21.8"

b) Montan State University (normal year)

irrigated ~~wheat~~ Spring Grain (MT Irrigation Guide)

ET 16.23

effective ppt 5.90

assuming 60% rainfall effective

seasonal rainfall $\frac{5.90}{.60} = 9.83$

ET corrected for elevation

$16.23 \times 1.0557 = 17.1''$

Belgrade Airport Spring Grain MT Irrigation Guide

ET = 15.97

effective ppt 4.19

assuming 60% effective

seasonal ppt $= \frac{4.19}{.6} = 7.0''$

ET corrected for elevation

$15.97 \times 1.0435 = 16.7''$

c) ET for non-irrigated land

Seasonal ppt would be about 80% effective

For MSU at Kalfa seasonal rainfall = 11"

Under dryland ~~more~~ the effective ppt %

would be greater - assumed to be 80%

∴ at MSU water reaching crops would be

about $11.1 \times .8 = 8.9''$

at Belgrade using same analysis

$7.38 \times .8 = 5.9''$

Even if these values are off by 100%, the conclusion is still that in the Gallatin Valley all the effective rainfall would be consumed by the native vegetation, or by non-irrigated crops

More complicated - better?

ET for non irrigated land

determined by first solving for Monthly mean rainfall

begin with monthly c.u. using index crop of alfalfa at ~~Belgrade airport~~ MSU (pg. 6~~9~~75, M.I.G. normal net app. 3.5"

	~~CU~~	CU
May	~~1.95~~	1.79
June	~~4.87~~	4.95
July	~~6.__~~	6.64
Aug		5.52
Sept		3.02

this is within 1% of values in Table 6, pg 27 TR21

Monthly ~~mean rainfall~~ effective rainfall

		Mean Rainfall
~~May~~	~~0.32~~	~~.5~~
~~June~~	~~1.5~~	~~2.0~~
~~July~~		
~~Aug~~		
Sept		

Effective PPT

		Mean Rainfall (from TR 21, Table 6
May	1.06	1.5
June	2.12	3.4
July	1.11	~~1.7~~ 1.7
Aug	1.13	1.7
Sept	1.24	1.9
	6.65	10.2

$\frac{6.65}{10.2}$ = .65 ~~shows~~ verifies previous assumption of .6

What is the % effective for non irrig crops,

The closest ~~crop in~~ irrigated crop to mimic native vegetation in the grass community would be Pasture Grasses as shown on pg 79, MIG

ET = 20.38" (w/o irrigation) with no irrigation ~~ET~~ C.U would be limited to the effective ppt which be in range of 9-12"

Camp Creek Hills Location

by inspection, elevation is ~ same as [illegible] Valley,
Latitude is the same,
Temp records not available, but using TR 21 procedure
but similar
ET by irrigated crops would be the same

Phreatophytes such as Willows, Cottonwood
[illegible]

If water available from Rat[illegible]

Table 6.--Average monthly effective rainfall[1/] as related to mean monthly rainfall and average monthly consumptive use

Monthly Mean Rainfall r_t Inches	Average Monthly Consumptive Use, u, in Inches 0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.00
	Average Monthly Effective Rainfall, r_e, in Inches										
0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.5	0.28	0.30	0.32	0.34	0.36	0.38	0.40	0.42	0.45	0.47	0.50
1.0	0.59	0.63	0.66	0.70	0.74	0.78	0.83	0.88	0.93	0.98	1.00
1.5	0.87	0.93	0.98	1.03	1.09	1.16	1.22	1.29	1.37	1.45	1.50
2.0	1.14	1.21	1.27	1.35	1.43	1.51	1.59	1.69	1.78	1.88	1.99
2.5	1.39	1.47	1.56	1.65	1.74	1.84	1.95	2.06	2.18	2.30	2.44
3.0		1.73	1.83	1.94	2.05	2.17	2.29	2.42	2.56	2.71	2.86
3.5		1.98	2.10	2.22	2.35	2.48	2.62	2.77	2.93	3.10	3.28
4.0		2.23	2.36	2.49	2.63	2.79	2.95	3.12	3.29	3.48	3.68
4.5			2.61	2.76	2.92	3.09	3.26	3.45	3.65	3.86	4.08
5.0			2.86	3.02	3.20	3.38	3.57	3.78	4.00	4.23	4.47
5.5			3.10	3.28	3.47	3.67	3.88	4.10	4.34	4.59	4.85
6.0				3.53	3.74	3.95	4.18	4.42	4.67	4.94	5.23
6.5				3.79	4.00	4.23	4.48	4.73	5.00	5.29	5.60
7.0				4.03	4.26	4.51	4.77	5.04	5.33	5.64	5.96
7.5					4.52	4.78	5.06	5.35	5.65	5.98	6.32
8.0					4.78	5.05	5.34	5.65	5.97	6.32	6.68

Note: Values below line exceed monthly consumptive use and are to be used for interpolation only.

1/ Based on 3-inch net depth of application. For other net depths of application, multiply by the factors shown below.

Net Depth of Application	(D)	.75	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	7.0
Factor	(f)	.72	.77	.86	.93	.97	1.00	1.02	1.04	1.06	1.07

Note: Average monthly effective rainfall cannot exceed average monthly rainfall or average monthly consumptive use. When the application of the above factors results in a value of effective rainfall exceeding either, this value must be reduced to a value equal the lesser of the two.

$$r_e = (0.70917\ r_t^{0.82416} - 0.11556)(10)^{0.02426u}\ (f)$$

where $f = (0.531747 + 0.295164D - 0.057697D^2 + 0.003804D^3)$

APPENDIX B

ESTIMATED MONTHLY AND SEASONAL CONSUMPTIVE USE

(SCS, TR-21 Balaney-Criddle Method)

County Gallatin

Weather Station Belgrade Airport 4547 N, 11109 W

Climatic zone Moderately Low (4) Elevation 4451 FT

Crop Pasture Grasses Normal net irrigation application 1.5 in

Planting date April 25 Harvest date October 20

MONTH	CONSUMPTIVE USE INCHES	EFFECTIVE PRECIPITATION INCHES Normal Year (50%)	EFFECTIVE PRECIPITATION INCHES Dry Year (80%)	NET IRRIGATION 1/ INCHES Normal Year (50%)	NET IRRIGATION 1/ INCHES Dry Year (80%)
JAN					
FEB					
MAR					
APR	.20	.10	.07	.00	.00
MAY	2.64	1.24	.88	.76	1.15
JUN	3.98	1.49	1.06	2.48	2.92
JUL	5.51	.69	.49	4.82	5.02
AUG	4.66	.79	.56	3.87	4.10
SEP	2.51	.75	.53	1.36	1.70
OCT	.77	.42	.30	.00	.00
NOV					
DEC					
TOTAL	20.28	5.49	3.89	13.29	14.89

Crop Beans, Snap Normal net irrigation application 1.5 in

Planting date June 1 Harvest date August 20

MONTH	CONSUMPTIVE USE INCHES	EFFECTIVE PRECIPITATION INCHES Normal Year (50%)	EFFECTIVE PRECIPITATION INCHES Dry Year (80%)	NET IRRIGATION 1/ INCHES Normal Year (50%)	NET IRRIGATION 1/ INCHES Dry Year (80%)
JAN					
FEB					
MAR					
APR					
MAY					
JUN	2.56	1.35	.95	.47	.86
JUL	5.65	.70	.49	4.95	5.15
AUG	3.70	.54	.38	2.41	2.57
SEP					
OCT					
NOV					
DEC					
TOTAL	11.91	2.58	1.83	7.82	8.58

1/ Included in computations is cary-over moisture which is assumed to be available within crop root zone at planting time or spring growth time. This value represents non-growing season precipitation equal to a normal net irrigation application, and is split between beginning and end of growing season.

APPENDIX B
ESTIMATED MONTHLY AND SEASONAL CONSUMPTIVE USE
(SCS, TR-21 Balaney-Criddle Method)

County Gallatin
Weather Station Belgrade Airport 4547 N, 11109 W
Climatic zone Moderately Low (4) Elevation 4451 FT

Crop Potatoes Normal net irrigation application 1.2 in
Planting date May 24 Harvest date September 17

MONTH	CONSUMPTIVE USE INCHES	EFFECTIVE PRECIPITATION INCHES Normal Year (50%)	EFFECTIVE PRECIPITATION INCHES Dry Year (80%)	NET IRRIGATION 1/ INCHES Normal Year (50%)	NET IRRIGATION 1/ INCHES Dry Year (80%)
JAN					
FEB					
MAR					
APR					
MAY	.23	.18	.13	.00	.00
JUN	2.27	1.28	.90	.44	.87
JUL	6.44	.69	.49	5.75	5.95
AUG	6.96	.84	.59	6.12	6.37
SEP	2.10	.43	.30	1.07	1.20
OCT					
NOV					
DEC					
TOTAL	18.00	3.41	2.42	13.39	14.39

Crop Small Vegetables Normal net irrigation application 1.2 in
Planting date June 4 Harvest date September 3

MONTH	CONSUMPTIVE USE INCHES	EFFECTIVE PRECIPITATION INCHES Normal Year (50%)	EFFECTIVE PRECIPITATION INCHES Dry Year (80%)	NET IRRIGATION 1/ INCHES Normal Year (50%)	NET IRRIGATION 1/ INCHES Dry Year (80%)
JAN					
FEB					
MAR					
APR					
MAY					
JUN	1.78	1.09	.77	.09	.41
JUL	4.70	.62	.44	4.08	4.26
AUG	3.53	.69	.49	2.29	2.51
SEP	.12	.07	.05	.00	.00
OCT					
NOV					
DEC					
TOTAL	10.12	2.47	1.75	6.46	7.18

1/ Included in computations is cary-over moisture which is assumed to be available within crop root zone at planting time or spring growth time. This value represents non-growing season precipitation equal to a normal net irrigation application, and is split between beginning and end of growing season.

APPENDIX B
ESTIMATED MONTHLY AND SEASONAL CONSUMPTIVE USE
(SCS, TR-21 Balaney-Criddle Method)

County Gallatin
Weather Station Bozeman, Mont. St. University 4540 N, 11103 W
Climatic zone Moderately Low (4) Elevation 4856 FT

MONTH	CONSUMPTIVE USE INCHES	EFFECTIVE PRECIPITATION: INCHES Normal Year (50%)	EFFECTIVE PRECIPITATION: INCHES Dry Year (80%)	NET IRRIGATION 1/ INCHES Normal Year (50%)	NET IRRIGATION 1/ INCHES Dry Year (80%)
Crop Pasture Grasses		Normal net irrigation application 3.5 in			
Planting date April 26		Harvest date October 13			
JAN					
FEB					
MAR					
APR	.17	.14	.10	.00	.00
MAY	2.71	1.87	1.39	.00	.00
JUN	4.04	2.01	1.50	1.15	2.19
JUL	5.53	1.05	.78	4.48	4.75
AUG	4.71	1.08	.80	3.48	3.91
SEP	2.66	1.21	.90	.00	.26
OCT	.56	.41	.31	.00	.00
NOV					
DEC					
TOTAL	20.38	7.77	5.77	9.11	11.11
Crop Peas		Normal net irrigation application 2.8 in			
Planting date May 24		Harvest date August 13			
JAN					
FEB					
MAR					
APR					
MAY	.37	.33	.25	.00	.00
JUN	3.72	1.93	1.44	.42	1.00
JUL	6.59	1.09	.81	5.50	5.78
AUG	2.18	.45	.34	.33	.44
SEP					
OCT					
NOV					
DEC					
TOTAL	12.86	3.81	2.83	6.25	7.23

1/ Included in computations is cary-over moisture which is assumed to be available within crop root zone at planting time or spring growth time. This value represents non-growing season precipitation equal to a normal net irrigation application, and is split between beginning and end of growing season.

APPENDIX B
ESTIMATED MONTHLY AND SEASONAL CONSUMPTIVE USE
(SCS, TR-21 Balaney-Criddle Method)

County Gallatin
Weather Station Bozeman Mont. St. University 4540 N, 11103 W
Climatic zone Moderately Low (4) Elevation 4856 FT

Crop Alfalfa Normal net irrigation application 3.5 in
Planting date May 14 Harvest date September 30

MONTH	CONSUMPTIVE USE INCHES	EFFECTIVE PRECIPITATION: INCHES Normal Year (50%)	EFFECTIVE PRECIPITATION: INCHES Dry Year (80%)	NET IRRIGATION 1/ INCHES Normal Year (50%)	NET IRRIGATION 1/ INCHES Dry Year (80%)
JAN					
FEB					
MAR					
APR					
MAY	1.79	1.06	.79	.00	.00
JUN	4.95	2.12	1.57	1.81	2.62
JUL	6.64	1.11	.83	5.53	5.81
AUG	5.52	1.13	.84	4.39	4.68
SEP	3.02	1.24	.92	.03	.35
OCT					
NOV					
DEC					
TOTAL	21.91	6.65	4.94	11.76	13.47

Crop Grain, Spring Normal net irrigation application 3.5 in
Planting date April 26 Harvest date September 3

MONTH	CONSUMPTIVE USE INCHES	EFFECTIVE PRECIPITATION: INCHES Normal Year (50%)	EFFECTIVE PRECIPITATION: INCHES Dry Year (80%)	NET IRRIGATION 1/ INCHES Normal Year (50%)	NET IRRIGATION 1/ INCHES Dry Year (80%)
JAN					
FEB					
MAR					
APR	.06	.06	.05	.00	.00
MAY	1.79	1.63	1.21	.00	.00
JUN	4.91	2.11	1.57	1.21	2.19
JUL	7.11	1.14	.85	5.63	6.10
AUG	2.35	.94	.70	.00	.00
SEP	.01	.01	.01	.00	.00
OCT					
NOV					
DEC					
TOTAL	16.23	5.90	4.38	6.83	8.35

1/ Included in computations is cary-over moisture which is assumed to be available within crop root zone at planting time or spring growth time. This value represents non-growing season precipitation equal to a normal net irrigation application, and is split between beginning and end of growing season.

APPENDIX B
ESTIMATED MONTHLY AND SEASONAL CONSUMPTIVE USE
(SCS, TR-21 Balaney-Criddle Method)

County Gallatin
Weather Station Belgrade Airport 4547 N, 11109 W
Climatic zone Moderately Low(4) Elevation 4451 FT

MONTH	CONSUMPTIVE USE INCHES	EFFECTIVE PRECIPITATION: INCHES Normal Year (50%)	Dry Year (80%)	NET IRRIGATION 1/ INCHES Normal Year (50%)	Dry Year (80%)

Crop Corn, Sweet Normal net irrigation application 1.2 in
Planting date June 5 Harvest date September 13

MONTH	CONSUMPTIVE USE INCHES	Normal Year (50%)	Dry Year (80%)	Normal Year (50%)	Dry Year (80%)
JAN					
FEB					
MAR					
APR					
MAY					
JUN	1.90	1.06	.75	.24	.55
JUL	5.43	.65	.46	4.79	4.97
AUG	5.51	.77	.55	4.74	4.96
SEP	1.28	.31	.22	.37	.46
OCT					
NOV					
DEC					
TOTAL	14.13	2.80	1.98	10.13	10.95

Crop Peas Normal net irrigation application 1.2 in
Planting date May 25 Harvest date August 13

MONTH	CONSUMPTIVE USE INCHES	Normal Year (50%)	Dry Year (80%)	Normal Year (50%)	Dry Year (80%)
JAN					
FEB					
MAR					
APR					
MAY	.30	.19	.13	.00	.00
JUN	3.61	1.37	.97	1.75	2.20
JUL	6.58	.69	.49	5.88	6.09
AUG	2.16	.32	.23	1.24	1.33
SEP					
OCT					
NOV					
DEC					
TOTAL	12.64	2.57	1.82	8.87	9.62

1/ Included in computations is cary-over moisture which is assumed to be available within crop root zone at planting time or spring growth time. This value represents non-growing season precipitation equal to a normal net irrigation application, and is split between beginning and end of growing season.

APPENDIX B

ESTIMATED MONTHLY AND SEASONAL CONSUMPTIVE USE
(SCS, TR-21 Balaney-Criddle Method)

County Gallatin
Weather Station Belgrade Airport 4547 N, 11109 W
Climatic zone Moderately Low (4) Elevation 4451 FT

MONTH	CONSUMPTIVE USE INCHES	EFFECTIVE PRECIPITATION: INCHES Normal Year (50%)	Dry Year (80%)	NET IRRIGATION 1/ INCHES Normal Year (50%)	Dry Year (80%)
Crop Turf		Normal net irrigation application 1.0 in			
Planting date April 25		Harvest date October 20			
JAN					
FEB					
MAR					
APR	.20	.09	.06	.00	.00
MAY	2.64	1.11	.79	1.15	1.50
JUN	3.98	1.34	.95	2.64	3.03
JUL	5.51	.62	.44	4.89	5.07
AUG	4.66	.70	.50	3.96	4.16
SEP	2.51	.67	.48	1.73	2.03
OCT	.77	.38	.27	.00	.00
NOV					
DEC					
TOTAL	20.28	4.91	3.48	14.37	15.80

Crop ______ Normal net irrigation application ______ in
Planting date ______ Harvest date ______

MONTH					
JAN					
FEB					
MAR					
APR					
MAY					
JUN					
JUL					
AUG					
SEP					
OCT					
NOV					
DEC					
TOTAL					

1/ Included in computations is cary-over moisture which is assumed to be available within crop root zone at planting time or spring growth time. This value represents non-growing season precipitation equal to a normal net irrigation application, and is split between beginning and end of growing season.

APPENDIX B
ESTIMATED MONTHLY AND SEASONAL CONSUMPTIVE USE
(SCS, TR-21 Balaney-Criddle Method)

County Gallatin
Weather Station Belgrade Airport 4547 N, 11109 W
Climatic zone Moderately Low (4) Elevation 4451 FT

MONTH	CONSUMPTIVE USE INCHES	EFFECTIVE PRECIPITATION: INCHES Normal Year (50%)	EFFECTIVE PRECIPITATION: INCHES Dry Year (80%)	NET IRRIGATION 1/ INCHES Normal Year (50%)	NET IRRIGATION 1/ INCHES Dry Year (80%)
Crop Wheat, Winter (Fall) Normal net irrigation application 1.5 in					
Planting date September 10 Harvest date October 14					
JAN					
FEB					
MAR					
APR					
MAY					
JUN					
JUL					
AUG					
SEP	1.15	.48	.34		
OCT	.80	.30	.21		
NOV					
DEC					
TOTAL	1.95	.78	.56		
Crop Wheat, Winter (Spring) Normal net irrigation application 1.5 in					
Planting date April 26 Harvest date August 4					
JAN					
FEB					
MAR					
APR	.26	.08	.06	.00	.00
MAY	3.96	1.33	.94	2.05	2.47
JUN	5.45	1.62	1.15	3.82	4.30
JUL	3.23	.61	.43	1.88	2.06
AUG	.03	.02	.01	.00	.00
SEP					
OCT					
NOV					
DEC					
TOTAL	12.92	3.67	2.60	7.75	8.82

1/ Included in computations is cary-over moisture which is assumed to be available within crop root zone at planting time or spring growth time. This value represents non-growing season precipitation equal to a normal net irrigation application, and is split between beginning and end of growing season.

APPENDIX B
ESTIMATED MONTHLY AND SEASONAL CONSUMPTIVE USE
(SCS, TR-21 Balaney-Criddle Method)

County Gallatin
Weather Station Belgrade Airport 4547 N, 11109 W
Climatic zone Moderately Low (4) Elevation 4451 FT

MONTH	CONSUMPTIVE USE INCHES	EFFECTIVE PRECIPITATION: INCHES Normal Year (50%)	Dry Year (80%)	NET IRRIGATION 1/ INCHES Normal Year (50%)	Dry Year (80%)
Crop Alfalfa		Normal net irrigation application 1.5 in			
Planting date May 12		Harvest date September 20			
JAN					
FEB					
MAR					
APR					
MAY	1.95	.78	.55	.42	.65
JUN	4.87	1.57	1.11	3.30	3.76
JUL	6.62	.74	.52	5.88	6.10
AUG	5.46	.82	.58	4.64	4.88
SEP	1.90	.51	.36	.64	.79
OCT					
NOV					
DEC					
TOTAL	20.80	4.43	3.14	14.87	16.16

MONTH	CONSUMPTIVE USE INCHES	EFFECTIVE PRECIPITATION: INCHES Normal Year (50%)	Dry Year (80%)	NET IRRIGATION 1/ INCHES Normal Year (50%)	Dry Year (80%)
Crop Grain, Spring		Normal net irrigation application 1.5 in			
Planting date April 25		Harvest date September 2			
JAN					
FEB					
MAR					
APR	.07	.04	.03	.00	.00
MAY	1.79	1.12	.80	.00	.29
JUN	4.90	1.57	1.11	3.27	3.78
JUL	7.01	.76	.54	6.25	6.47
AUG	2.19	.68	.49	.75	.95
SEP					
OCT					
NOV					
DEC					
TOTAL	15.97	4.19	2.96	10.28	11.50

1/ Included in computations is cary-over moisture which is assumed to be available within crop root zone at planting time or spring growth time. This value represents non-growing season precipitation equal to a normal net irrigation application, and is split between beginning and end of growing season.

Table 6.--Average monthly effective rainfall[1/] as related to mean monthly rainfall and average monthly consumptive use

Monthly Mean Rainfall r_t Inches	Average Monthly Consumptive Use, u, in Inches 0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.00
	Average Monthly Effective Rainfall, r_e, in Inches										
0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.5	0.28	0.30	0.32	0.34	0.36	0.38	0.40	0.42	0.45	0.47	0.50
1.0	0.59	0.63	0.66	0.70	0.74	0.78	0.83	0.88	0.93	0.98	1.00
1.5	0.87	0.93	0.98	1.03	1.09	1.16	1.22	1.29	1.37	1.45	1.50
2.0	1.14	1.21	1.27	1.35	1.43	1.51	1.59	1.69	1.78	1.88	1.99
2.5	1.39	1.47	1.56	1.65	1.74	1.84	1.95	2.06	2.18	2.30	2.44
3.0		1.73	1.83	1.94	2.05	2.17	2.29	2.42	2.56	2.71	2.86
3.5		1.98	2.10	2.22	2.35	2.48	2.62	2.77	2.93	3.10	3.28
4.0		2.23	2.36	2.49	2.63	2.79	2.95	3.12	3.29	3.48	3.68
4.5			2.61	2.76	2.92	3.09	3.26	3.45	3.65	3.86	4.08
5.0			2.86	3.02	3.20	3.38	3.57	3.78	4.00	4.23	4.47
5.5			3.10	3.28	3.47	3.67	3.88	4.10	4.34	4.59	4.85
6.0				3.53	3.74	3.95	4.18	4.42	4.67	4.94	5.23
6.5				3.79	4.00	4.23	4.48	4.73	5.00	5.29	5.60
7.0				4.03	4.26	4.51	4.77	5.04	5.33	5.64	5.96
7.5					4.52	4.78	5.06	5.35	5.65	5.98	6.32
8.0					4.78	5.05	5.34	5.65	5.97	6.32	6.68

Note: Values below line exceed monthly consumptive use and are to be used for interpolation only.

1/ Based on 3-inch net depth of application. For other net depths of application, multiply by the factors shown below.

Net Depth of Application	(D)	.75	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	7.0
Factor	(f)	.72	.77	.86	.93	.97	1.00	1.02	1.04	1.06	1.07

Note: Average monthly *effective* rainfall cannot exceed average monthly rainfall or average monthly consumptive use. When the application of the above factors results in a value of effective rainfall exceeding either, this value must be reduced to a value equal the lesser of the two.

$$r_e = (0.70917\, r_t^{0.82416} - 0.11556)(10)^{0.02426u}\,(f)$$

$$\text{where } f = (0.531747 + 0.295164D - 0.057697D^2 + 0.003804D^3)$$

A SUGGESTED METHOD FOR ESTIMATING EVAPOTRANSPIRATION BY NATIVE PHREATOPHYTES

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DRAFT

Work done in cooperation with the California Department of Water Resources

Abstract.—A graph and table have been developed for selecting values of the coefficient K to be used in the Blaney-Criddle formula for estimating evapotranspiration by native phreatophytes. Values of K are dependent on the species of phreatophyte, the density of growth, and the depth to water table.

In reconnaissance studies of the hydrology of arid basins it is often desirable to make rough estimates of the average annual evapotranspiration by native phreatophytes. These plants usually draw the great bulk of their water from the underlying ground-water body, either directly or through the capillary fringe. The amount of water transpired depends not only on climatic factors, but also on plant species, thickness of the foliage canopy, density of cover (percentage of land area shaded by foliage), and depth to water table. Many researchers—for example, H. F. Blaney, W. D. Criddle, T. W. Robinson, and J. S. Gatewood—using a variety of methods have obtained and published data showing the effect of various factors on the water use by phreatophytes, but nowhere in the literature is there unified data showing the effect of all factors on the water use. In other words, no simple solution is available for the problem of estimating the use of water in a given locality (1) by a given species of phreatophyte, (2) for a given density of growth, and (3) for a given depth to water table. This paper attempts to provide a solution of sorts to that problem.

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BLANEY-CRIDDLE FORMULA

Of the several empirical formulas used for estimating evapotranspiration, the most popular is the Blaney-Criddle formula. One of the reasons for this popularity is the fact that the only climatic information required for application of the formula is mean monthly temperature which, if not available for a study site, may be inferred from records for the nearest U.S. Weather Bureau stations. In addition, the formula differentiates between vegetal species, a distinction that is not made by most of the other formulas.

The Blaney-Criddle method is based on the assumption that with ample moisture available, evapotranspiration is affected primarily by temperature, duration of daylight, and vegetal species. For a complete description of the method, the reader is referred to a report by Blaney and Criddle (1962). In brief, the Blaney-Criddle equation for evapotranspiration is

$$U = K\Sigma \frac{(T)(p)}{100},$$

where U is evapotranspiration during the growing period,

K is an empirical consumptive-use coefficient that is primarily dependent on the vegetal species,

p is the monthly percentage of total daytime hours in the year,

and

T is the mean monthly temperature, in degrees Fahrenheit.

Table 1 gives values of p for the various latitudes between 24° and 50° north. In using the equation, the monthly products of T and p are added for all months

[From Blaney and Criddle, 1962, p. 48]

Month	24	26	28	30	32	34	36	38	40	42	44	46	48	50
	Latitude, in degrees north of equator													
January	7.58	7.49	7.40	7.30	7.20	7.10	6.99	6.87	6.73	6.60	6.45	6.30	6.13	5.98
February	7.17	7.12	7.07	7.03	6.07	6.91	0.87	6.79	6.73	6.68	6.59	6.50	6.42	6.32
March	8.40	8.40	8.39	8.38	8.37	8.38	8.35	8.34	8.30	8.28	8.25	8.24	8.22	8.25
April	8.60	8.64	8.68	8.72	8.75	8.80	8.85	8.90	8.92	8.97	9.04	9.09	9.15	9.25
May	9.30	9.37	9.46	9.53	9.63	9.72	9.81	9.92	9.99	10.10	10.22	10.37	10.50	10.69
June	9.19	9.30	9.38	9.49	9.60	9.70	9.83	9.95	10.08	10.21	10.38	10.54	10.72	10.93
July	9.41	9.49	9.58	9.67	9.77	9.88	9.99	10.10	10.24	10.37	10.50	10.66	10.83	10.99
August	9.05	9.10	9.16	9.22	9.28	9.33	9.40	9.47	9.56	9.64	9.73	9.82	9.92	10.00
September	8.31	8.32	8.32	8.34	8.34	8.36	8.36	8.38	8.41	8.42	8.43	8.44	8.45	8.44
October	8.10	8.00	8.02	7.99	7.93	7.90	7.85	7.80	7.78	7.73	7.67	7.61	7.56	7.43
November	7.43	7.36	7.27	7.19	7.11	7.02	6.92	6.82	6.73	6.63	6.51	6.38	6.24	6.07
December	7.46	7.35	7.27	7.14	7.05	6.92	6.79	6.66	6.53	6.39	6.23	6.05	5.86	5.65
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

[1] Computed from Smithsonian Meteorological tables (List, 1951, table 171).

the growing period. Average monthly products of T and p for numerous locations in the western United States are tabulated in the report by Blaney and Criddle (1962, p. 44–49).

BLANEY-CRIDDLE COEFFICIENT

\# Don't use K= with this!

The only difficulty presented by the Blaney-Criddle formula is the selection of the proper value of the all-important coefficient, K. This coefficient, as implied earlier, depends not only on the vegetal species, but also on the depth to the water table and on the density of growth. In addition, K has a regional variation because mean monthly temperature is only an index to the many climatic factors that affect evapotranspiration. In those parts of the arid Southwest, however, where the use of water by native phreatophytes is a significant factor in the hydrologic budget, the variation in K attributable to climatic factors is less important than the variation attributable to vegetal species, density of growth, and depth to the water table. The literature was examined, therefore, to obtain a means of relating K to the latter three factors. Density of growth, as used in this paper, is a combination of two elements—thickness of foliage canopy and density of cover—and is expressed qualitatively as dense, medium, and light. No greater refinement in defining growth characteristics was warranted for this study.

From the welter of information on evapotranspiration by phreatophytes—much of it inconsistent—several reports were selected as being most useful for a generalized study of the coefficient, K. Even those selected reports contain some inconsistent data, and personal judgment was required in deciding what information to ignore and how to best manipulate the remaining data. The net result of this subjective process was figure 1, which is the end product of this paper.

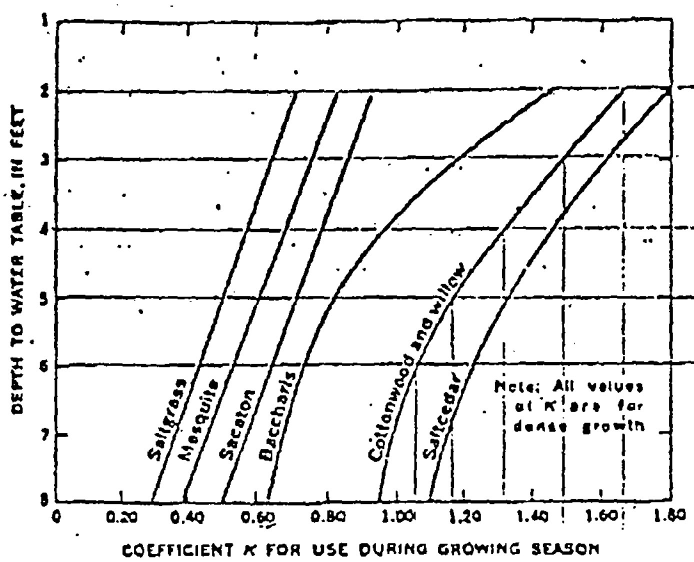

FIGURE 1.—Graph for estimating value of Blaney-Criddle coefficient K in determination of water use by phreatophytes in southwestern United States. (To be used only in the absence of quantitative data at a site.)

The graph in figure 1 gives values of K, for the growing season, for dense growths of various phreatophytes, and shows the variation of K with depth to water table. A K value of 1.30 is recommended for dense growths of hydrophytes, which are plants, such as tule and sedge, that live wholly or partly submerged in water or in saturated soil that is intermittently submerged. Factors for adjusting K values for the effect of density of growth of both phreatophytes and hydrophytes are given in the following tabulation. These factors were derived from a report by Blaney (1954, table 3).

Growth	Factor by which to multiply K value for density of growth
Dense	1.00
Medium	.85
Light	.70

figure 1. The three plotted values of K for saltgrass in figure 2 were obtained from an investigation in inland areas of southern California. A straight line was fitted to the points on the basis of the following statement by Muckel (1966, p. 29): "Several studies have been conducted in the arid Southwest that show a straight-line relationship between depth to ground water and water use by saltgrass." The two plotted values of K for sacaton were obtained from an investigation near Carlsbad, N. Mex. There was some question as to how to use the data for mesquite. The report by Blaney and Hanson (1965), from which the values for sacaton were obtained, gave K values of 0.65 and 0.75 for mesquite but did not indicate the corresponding depths to water table. For the purpose of this study the curve for mesquite was arbitrarily drawn midway between those for saltgrass and sacaton; the shaded area was added to the graph to show the range of K values given for mesquite.

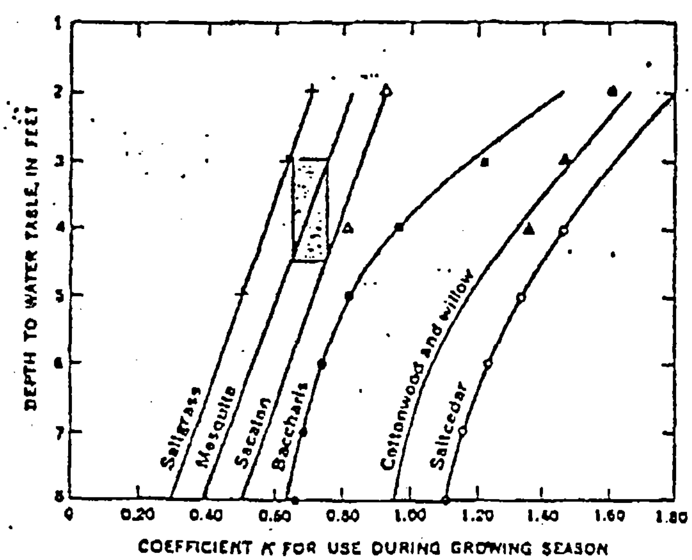

FIGURE 2.—Derivation of curves for relation of Blaney-Criddle coefficient K to depth to water table for various phreatophytes. Source of data: Saltgrass, Blaney and Muckel (1955, table 5, p. 318). Mesquite, Blaney and Hanson (1965, table 22). Sacaton, Blaney and Hanson (1965, table 20). Baccharis, Gatewood and others (1950, fig. 39) (inches converted to K values by use of $F=65$ for Safford, Ariz., and a tank coefficient of 0.85). Cottonwood and willow, Blaney and Hanson (1965, table 20). Saltcedar, Gatewood and others (1950, fig. 39) (inches converted to K values by use of $F=65$ for Safford, Ariz., and a tank coefficient of 0.85). The shaded area for mesquite was added to the graph to show the range of K values.

made by Gatewood and others in the Safford Valley, Ariz. In that study evapotranspiration was reported in inches of water. The absolute values of evapotranspiration were converted to corresponding K values by using a figure of $F=65$ in the Blaney-Criddle formula for Safford Valley, where $F=\Sigma(Tp)/100$. A tank coefficient of 0.85 was applied to the K values so derived, as suggested by data from Gatewood and others (1950, p. 194). In developing figure 2 considerable flexibility was used in fitting a curve to the plotted values of K for baccharis where depths to water table were less than 4 feet. The values of K used for cottonwood were obtained from a study made in southern California; those values were assumed to be appropriate also for willows. Values of K for saltcedar were determined from Safford Valley data by applying the same procedures used in the determination of K for baccharis.

SUMMARY

Figure 1, which provides values of the coefficient K for use in the Blaney-Criddle formula, was derived by applying somewhat subjective reasoning to selected data in an effort to obtain a practical method for making rough estimates of evapotranspiration by native phreatophytes in southwestern United States. The values of K from figure 1 should be used only in the absence of quantitative evapotranspiration data, at sites where the time and expense required for a quantitative study are not warranted.

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List, R. J., 1951, Smithsonian meteorological tables: Smithsonian Inst., Wasington, D.C., 527 p.

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Attachment B

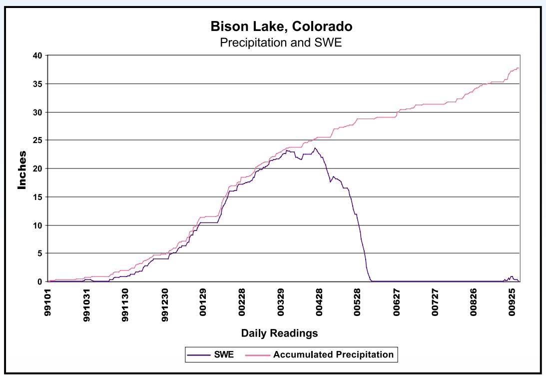
Snotel Literature

Data Quality

Each midnight (2400 hour) certain sensors must pass a limited automated computer-screening program that flags data that fails minimum requirements before the data are placed into the CCF database. Manual checking of the quality controlled data is done by the DCO's and reedited if necessary. These weekly edits are loaded into the database. A final edit is completed annually for each site prior to archiving.

Data Management and Accessibility

Remote site data is stored and managed at the National Water and Climate Center. Data can be accessed by direct logon with user accounts, hardcopy and in real-time via the internet at *www.wcc.nrcs.usda.gov.* Various analysis, reports and products can be found at this site in addition to the raw data.



Example of snow water equivalent and accumulated precipitation plot for Bison Lake SNOTEL, Colorado (Elevation 10,880', Colorado River Basin)

For More Information

contact the NRCS State Office in any of the western states; their Web pages can be found under "Links", line 5, under "Water Supply" on the NWCC homepage (see below).

Alaska: 907-271-2424 ext. 113
Arizona: 602-280-8841
California: 530-792-5624
Colorado: 720-544-2852
Idaho: 208-378-5741
Montana: 406-587-6844
Nevada: 775-784-5878 ext. 151
New Mexico: 505-761-4436
South Dakota: 406-587-6844
Oregon: 503-414-3266
Utah: 801-524-5213
Washington: 360-428-7684
Wyoming: 307-261-6481

Water & Climate Monitoring Branch Leader
National Water and Climate Center
101 SW Main St., Suite 1600
Portland, OR 97204
Phone: 503-414-3031 Fax: 503-414-3101

www.wcc.nrcs.usda.gov

The Natural Resources Conservation Service provides leadership in a partnership effort to help people conserve, maintain, and improve our natural resources and environment.

February 2003

United States Department of Agriculture
NRCS Natural Resources Conservation Service

National Water and Climate Center

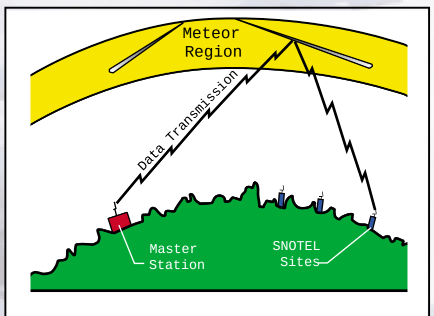
SNOTEL
(SNOwpack TELemetry)

SNOTEL

Introduction
The Natural Resources Conservation Service (NRCS) installs, operates and maintains an extensive, automated system designed to collect snowpack and related climatic data in the Western United States and Alaska. This system, called SNOTEL (for SNOwpack TELemetry), operates over 660 remote sites in mountain snowpack zones. Congress mandated NRCS (then the Soil Conservation Service) in the mid-1930's "to measure snowpack in the mountains of the West and forecast the water supply." Manual measurement of snow courses was the norm until 1980.

SNOTEL now provides reliable and efficiently collected data needed to produce water supply forecasts and to support the resource management activities of NRCS and others.

The modern SNOTEL network also serves climate studies, air and water quality investigations, climate changes, and endangered species habitat. The high-elevation watershed locations, broad coverage, and real-time operation of the network provide important data to researchers, river and reservoir managers, emergency managers for natural disasters such as floods and droughts, and for power generation.



SNOTEL Meteor-burst System

Meteor Burst Technology
SNOTEL uses meteor burst communication technology to communicate data in near real-time. VHF radio signals are reflected at a steep angle off the ever present band of ionized meteorites existing from about 50 to 75 miles above the earth. Satellites are not involved; NRCS operates and controls the entire system.

These sites are generally located in remote high-mountain watersheds where access is often difficult or restricted. Access for maintenance by NRCS and cooperators includes various modes from hiking and skiing to helicopters.

SNOTEL sites are designed to operate unattended and without maintenance for up to a year or longer. Batteries are charged by solar cells. Six NCRS Data Collection Offices (DCO) monitor daily site statistics and provide maintenance response.

The NRCS operates three meteor burst master stations located near Boise, Idaho, Ogden, Utah and Anchorage, Alaska. The master stations gather the remote site data and forward it to the Central Computer Facilities (CCF) located at the National Water and Climate Center (NWCC) in Portland, Oregon. At the CCF, it is converted to engineering units and is initially screened for errors, databased and made available to the public via the NWCC web site (http://www.wcc.nrcs.usda.gov).

SNOTEL System Capabilities
The basic SNOTEL site provides snowpack water content via pressure sensing snow pillow, snow depth, all-season storage precipitation accumulation, and air temperature with daily maximums, minimums, and averages.

The newest SNOTEL sites are enhanced with new hardware consisting of a meteor burst radio and datalogger. Many of these new SNOTEL sites provide complete weather station functions along with soil moisture and temperature measurements at various depths.

The atmospheric sensor data is generally acquired every 10 seconds, while the soil moisture and soil temperature measurements are done every 15 minutes.

Standard SNOTEL Site Configuration
(Daily Values Archived)

Parameter Measured	Data Sensing
Air Temperature	Shielded thermistor
Precipitation	Storage type gage
Snow Water Content	Snow pillow device and a pressure transducer
Snow Depth	Sonic sensor

Enhanced SNOTEL Site Configuration
(Generally Report Hourly.
Also includes Standard Site Configuration.)

Parameter Measured	Data Sensing
Barometric Pressure	Silicon capacitive pressure sensor
Relative Humidity	Thin film capacitance-type sensor
Soil Moisture	Dielectric constant measuring device. Measurements are taken at standard depths of 2", 4", 8", 20", and 40"
Soil Temperature	Encapsulated thermistor. Typical measurements are at 2", 4", 8", 20" and 40" depths.
Solar Radiation	Pyranometer
Wind Speed and Direction	Propeller type anemometer

Other sensors can be added to any of the enhanced SNOTEL sites such as water quality sensors.

System performance is usually above 99%. Data from missing reports are estimated to provide a serially complete data set.

Attachment C

Information Regarding Domestic Water Consumption

Colorado State Engineers Internal Memorandum

Technical Note

Internal Technical Memorandum from Colorado (Attached)

Attached is an internal memorandum from the Colorado State Engineer's office developed by Mr. Kenneth R. Wright, P.E., Chief Engineer. It discusses historic estimates and then a highly detailed research study conducted in Colorado for the purpose of quantifying more accurate estimates of residential consumptive use (CU). Based upon that study, it was determined that the most representative residence CU is from 0.455 to 1.365 gallons per capita per day (gpcd) [see last page of this attachment]. Other losses were quantified but they were related to waste water treatment plant CU associated with public water supply systems. User's of exempt wells do not typically use waste water treatment plants, but rather on-site treatment systems.

Montana Department of Environmental Quality (DEQ) generally assumes that a typical occupancy for each residence is 2.5 people. Using this assumption, the above values would be multiplied by 2.5 and that would equate to a CU per household ranging from 1.14 to 3.41 gallons per day (gpd).

Furthermore, a typical demand of 100 gpcd is assumed in Montana per household. Thus, a typical household of 2.5 people would use about 250 gpd. The CU of 1.14 and 3.41 gpd versus a demand of 250 gpd equates as a percentage to 0.5% to 1.4 % of pumped water.

Hence, the value of 2 % used in the text of the main body of the report should be considered conservative.

M E M O R A N D U M

TO: Kenneth R. Wright, P.E.; Chief Engineer

FROM: Dwight Kimsey/Patricia Flood

P. Flood D. Kimsey

DATE: December 31, 1987

SUBJECT: Domestic Consumptive Use - Summary

The Regis-Maryvale system is designed to supply 100 gallons per capita per day (gpcd) plus the amount required for summer irrigation. The actual use rate within the house is expected to be from 50 gpcd to 75 gpcd. This provides a cushion of at least 25 gpcd supply for line losses, fire-fighting, street cleaning, and other uses.

The in-house consumptive use (CU) was divided into two parts: (1) water loss within a residential unit and (2) water loss from the wastewater treatment plant. Irrigation use is not included.

In-house water use rates proposed by various authors were reviewed and Table 1 prepared to reflect the literature.

TABLE 1
WATER USE RATES FOR 50 AND 75 GPCD RATES

Item	Water Use, Gallons Per Capital Per Day	
	50 gpcd	75 gpcd
Water Closet	20.87	24.98
Shower	15.51	29.98
Hand Wash	6.64	8.99
Clothes Washer	3.76	6.00
Dish Washer	1.57	3.30
Kitchen Uses	1.55	1.64
Other Uses	0.10	0.11
Total	50.00	75.00

The 75 gpcd rate includes a higher water use allownce for showers, clothes washer and other high CU items in order to maximize the range of CU.

WRIGHT WATER ENGINEERS, INC.

In addition, the higher use rate was assigned the maximum calculated and/or measured CU in order to maximize the range of actual CU. The 75 gpcd use rate yielded an actual CU of 2.16 gpcd. This is a maximum actual CU and not an average.

Table 2 shows the in-house consumptive use for the 50 and 75 gpcd rates.

TABLE 2

Item	Water Use, Gallons/Day	
	50 gpcd	75 gpcd
Water closet	0.0069	0.0136
Shower	0.248	0.504
Hand Wash	0.1330	0.1800
Clothes Washer	0.128	0.325
Dish Washer	0.024	0.051
Kitchen Uses	0.069	0.230
Other Uses	0.058	0.060
Sewer Vent Loss	0.0006	0.0010
Subtotal	0.6675	1.3646
Human Consumption	-0.213	-0.213
Subtotal	0.4545	1.1516
Sewage Lagoon	0.675	1.0125
Total	1.13 gpcd	2.16 gpcd

The human consumption credit is due to two factors: (1) humans metabolize fats, carbohydrates and protein into water and other by-products and (2) an estimated 50% of the water intake comes from food and beverages purchased from sources outside the municipal water supply.

SUMMARY

The calculated domestic consumptive use (CU) for the Regis Maryvale property ranges between 1.130 gpcd and 2.377 gpcd. Actual in-house CU varied from 0.455 gpcd to 1.152 gpcd. Losses from the wastewater treatment plant added 0.675 gpcd and 1.0125 gpcd to the ranges. Irrigation and other outside use was not included. Leakage from the proposed system should be very small. Burial below the frost line assumes that any leakage will return to the river via groundwater with negligible loss.

Based upon a water system planning per capita figure of 100 gallons per day and per capita consumptive use of 1.13 to 2.38 gallons per capita day, the percentage consumptive use is 1.1 to 2.4 percent.

DWK/PKF:klr
(1.4)
831-029.030

TECHNICAL MEMORANDUM

TO: Kenneth R. Wright, P.E.; Chief Engineer

FROM: Dwight W. Kimsey and Patricia K. Flood, P.E.

P. Flood
D. Kimsey

DATE: December 31, 1987

SUBJECT: DOMESTIC CONSUMPTIVE USE

INTRODUCTION

The consumptive use (C.U.) of water used inside a residence has been estimated by water engineers subjectively for some thirty years in Colorado. This in-house (domestic) C.U. has defied direct measurement because of its small magnitude. The percent of C.U. is less than the normal accuracy of meters. Leaky sewer lines also contribute to the difficulty of measuring. Wright Water Engineers has undertaken a deterministic approach to measurement of in-house C.U.

This Technical Memorandum presents analyses and data related to the determination of in-house consumptive use of water. The in-house consumptive use is analyzed in two parts: (1) water loss from the time entering and leaving a residential unit; and (2) water loss from wastewater treatment process until return to the stream. Water use and (C.U.) are expressed in gallons per capita per day (gpcd). Regis-Maryvale has an elevation of approximately 8,700 feet. Future wastewater treatment will be at the Fraser, Colorado plant which is at an elevation of about 8,500 feet. The evaporation rates and water holding capacity of air are based on 8,700 feet elevation.

It has been determined that the residential C.U. of water ranges from 0.455 gpcd to a reasonable maximum rate of 1.365 gpcd. The C.U. from the wastewater plant to river is 1.35 percent. The total in-house C.U. of water ranges from 1.130 gpcd to 2.378 gpcd.

WRIGHT WATER ENGINEERS, INC.

REVIEW OF LITERATURE

The American Water Works Association (AWWA, 1984) estimates the following rates of use for various fixtures for the United States, as given in Table 1.

TABLE 1

HOUSEHOLD FIXTURE USE RATE

Laundry	20 to 45 gal. per load
Shower	20 to 30 gal. per shower
Tub Bath	30 to 40 gal. per bath
Dish Washing	15 to 30 gal per load
Toilet	3.5 to 7 gal. per flush
Drinking	1 to 2 qt. per day per person
Garbage Disposal	5 gal. per day

A standard engineering reference by Metcalf and Eddy, Inc., Wastewater Engineering, published by McGraw Hill, gives the fixture water use rates in the following Table 2.

TABLE 2

RESIDENTIAL UNIT FIXTURE WATER USE RATE IN GCD

Private dwelling with meter	50 to 75 gpcd
Water closet, tank	4 to 6 gal. per use
Wash basin	1.5 gal. per use
Bath	30 gal. per use
Shower	25 to 30 gal. per use
Automatic washing machine	6.5 to 9 gpcd
Automatic washing machine	30 to 50 gal. per load
Automatic dish washer	6 gal. per load
Garbage disposal	3 to 4 gpcd

Actual measured C.U. by fixture or use was not found in the literature.

A study for Colorado Ski Country USA, prepared by Wright Water Engineers in February 1986, concluded that in-house C.U. probably ranged from 2 to 5 percent loss. "The limited data that were collected are consistent with the estimated range of 2 to 5 percent; a C.U. large enough to be detected, in view of the experimental variation, was not detected."

Studies in Westminster by W. W. Wheeler, P.E., prior to 1960 indicated a typical in-house C.U. of 2.5 percent. Later studies by Mr. Al Hogan of W.W. Wheeler and Associates confirmed the reasonableness of 2.5 percent.

A Berkeley, California, study (Dunne, 1978) showed an average in-house use of 56 gpcd during the winter. A Northglenn, Colorado (Kimsey, unpublished) study measured 55.5 gpcd from October 24, 1986 to April 17, 1987. A study of 30 homes in Northglenn (Danielson, 1980) indicated a 72 gpcd per home domestic use without irrigation.

METHOD OF INDEPENDENT ANALYSES

Based on literature review augmented by actual single-family residential unit measurements of water use in a Northglenn household, the range of reasonable in house domestic water use was tabulated. Consumptive use factors were calculated based on measured losses where measurement was possible. A range of C.U. was calculated. Changes in relative humidity were based on saturated air at 70 F at 8,700 feet elevation and average pressure which holds .00115 pounds of water vapor per cubic foot of dry air.

In addition to the Northglenn testing, an independent analysis was conducted by Dr. Herbert Johnson, P.E.* of Herbson Engineering, Boulder, Colorado for an indepth evaluation of evaporative water loss of the four highest water using fixtures.

*Dr. Herbert Johnson is Associate Professor, Emeritus of Mechanical Engineering at the University of Colorado in Boulder. He is an expert in thermodynamics and has published technical work in this field.

These evaluations have been incorporated into the consumptive use analyses presented here.

The AWWA and Metcalf and Eddy, Inc. water use rates are in close agreement and are the basis for the domestic use rate Table 3.

TABLE 3
RESIDENTIAL DOMESTIC USE RATE

Total	50 to 75 gpcd
Water Closet	3.5 to 7 gallons per use
Shower	20 to 35 gallons per use
Hand Wash	0.5 to 1.5 gallons per use
Clothes Washer	20 to 45 gallons per use
Clothes Washer	4 to 9 gpcd
Dish Washer	6 to 15 gallons per load
Bath	30 to 40 gallons per use
Surface Cleaning	1 to 5 gallons per use
Garbage Disposal	5 gallons per day
Garbage Disposal	3 to 4 gpcd
Cooking (not eaten)	0.3 to 2 gpcd
Human Consumption	0.2 to 2 gpcd
Coffee Pot	0.1 to 0.3 gal per user per day
Floor Scrubbing	2 to 3 gallons per use
Miscellaneous	less than 1 gpcd

Using the above limits and estimates of the number of uses per day, low C.U. and reasonable maximum C.U. figures were determined. The validity of this approach is based on the fact that the sum of the individual uses must balance within the given total gpcd range.

RANGE OF USES

For residential C.U. determination, a 50 gpcd rate is selected, together with a reasonable maximum of 75 gpcd as an upper limit. The 75 gpcd rate was assigned increased rates for showers, clothes washing, and cooking, which have high C.U. Table 4 presents the range of water use rates.

TABLE 4

WATER USE RATES FOR 50 AND 75 GPCD RATE

Item	Water Use, gallons/day 50 gpcd	75 gpcd	Use as % of Total
Water Closet	20.87	24.98	41.7 - 33.3
Shower	15.51	29.98	31.0 - 40.0
Hand Wash	6.64	8.99	13.3 - 12.0
Clothes Washer	3.76	6.00	7.5 - 8.0
Dish Washer	1.57	3.30	3.1 - 4.4
Bath	-	-	-
Surface Cleaning	0.55	0.60	1.1 - 0.8
Disposal	0.39	0.40	0.8 - 0.5
Cooking	0.28	0.30	0.6 - 0.4
Human Consumption	0.22	0.22	0.4 - 0.3
Coffee	0.11	0.12	0.2 - 0.2
Floor Scrubbing	0.042	0.050	0.1 - 0.1
Miscellaneous	0.058	0.060	0.1 - 0.1
Totals:	50.000	75.000	

HUMAN CONSUMPTION

Humans augment the municipal water supply by consumption of fluids from outside the home and conversion of food stuffs to water by metabolism.

Water production from the metabolism of food and importation of fluids results in a net gain of 805 ml/person/day or 0.213 gpcd of augmentation. A range of 0.1 to 0.3 gpcd covers community differences in amount of strenuous exercise and quantity of imported foods and liquids.

TABLE 5
HUMAN WATER INPUT AND OUTPUT
(values given in milliliters, ml)

Input				Output			
Item	Input [ml]	Water Supply [ml]	Outside Source [ml]	Item	Output [ml]	Sewer [ml]	Other [ml]
Fluid	1350	700	650	Urine	1450	1450	0
Food	850	120	730	Feces	175	175	0
Metabolic	300	0	300	Insensible*	125	0	125
				Skin	375	0	375
				Lungs	375	0	375
Totals:	2500	820	1680		2500	1625	875

Outside Source Input (1680 ml) - Other Output (875 ml) = 805 ml gain

* Insensible loss includes perspiration based on 2000 Calories per day diet. Strenuous exercise or hot climates will increase this loss.

A medical professional, Loretta O'Brien, reviewed the above input and output of humans and compared the figures to several medical references. Water consumed in food with various caloric intake rates varied slightly between references. Mrs. O'Brien explained higher caloric intake resulted in more metabolic water (assuming constant body weight) in the urine, until perspiration started using water. In the Fraser area, loss due to perspiration will be low due to low air temperatures. This metabolized water augments or reduces the actual percentage of in-house consumptive use.

RESIDENTIAL CONSUMPTIVE USE DETERMINATIONS

The methodology for the determination of C.U. by category of use is discussed in the following paragraphs. Calculations involving changes in relative humidity are based upon saturated air at 8,700 feet at 70° F which contains .00115 pounds of water per cubic foot of dry air. One gallon of water weight 8.34 pounds. Therefore, saturated air at the above conditions contains 1.38 gallons per 10,000 cubic feet dry air. For a 1-percent increase in humidity, the volume of water in air increases .00014 gallons. The following analyses of C.U. for various water uses is based on measurements of water C.U. parameters taken in actual single-family residences. The unit parameters are then applied to a hypothetical residential unit with 2.75 people.

Water Closet

Water closet use is based on 2.75 people per unit and 6 water closet flushes per person per day.

Each flush uses 3.6 gallons of water causing a volume change in the tank of .45 cubic feet. The exchanged air in the tank changes from an estimated 30 percent to 70 percent relative humidity. Additional losses occur from evaporation from the bowl. Using an annual evaporation rate of 3 feet per year and a surface area of .60 ft^2 the calculations are as follows:

Tank Water

Vapor: $.40 \times .45\ ft^3 \times .00014\ \frac{gal\ water}{ft^3\ air} \times 6\ flush/cap/day = .0002\ gpcd$

Bowl Surface Evaporation $\frac{.60ft^2 \times 3\ ft/yr \times 7.48\ gal/ft^3}{2.75\ persons \times 365\ days/yr.} = .0134\ gpcd$

Combining bowl and tank evaporation with the bowl lid always open yields .0136 gpcd. If the bowl lid is closed one half of the time the total evaporation is .0069 gpcd.

Water closet C.U. ranges from .007 to .014 gpcd.

Shower

Shower C.U. will vary with the rate of water flow, shower construction, and the ventilation of the room.

C.U. was determined by two methods. The first evaluated losses due to the change in relative humidity of the air in a ventilated room as a standard (2 to 4 gpm) flow shower was operating.

The second method modeled the system as a cooling tower, air and water flow system. The system was evaluated as being of constant pressure and adiabatic (no heat loss or gain) with respect to surroundings. This was evaluated for low (1.2 gpm) and high flow (2.5 gpm) shower heads and for ventilated and unventilated rooms.

For the first method, a standard shower head was used. The rate of flow was measured using a bucket and a stopwatch. The length of a typical shower was assumed to be 10 minutes.

This typical bathroom measured 5' x 8' x 8' or 320 cubic feet volume. A 120 cfm exhaust fan was used in this room and was adequate to prevent fogging of mirrors. For these calculations, a 170 cfm fan is assumed for conservative results.

These calculations assume that the air entering the room is at 30 percent relative humidity (RH), and increased to 90 percent RH before being exhausted from the room. Water splash was measured by weighing towels dry and after being used to dry shower surfaces.

The C.U. per shower calculations are summarized as follows:

Water evaporated and exhausted:

$$320 \text{ ft}^3 + (170 \text{ ft}^3/\text{min} \times 10 \text{ min}) = 2020 \text{ ft}^3$$

$$2020 \text{ ft}^3 \times .00014 \text{ gal/ft}^3 \times (0.9 - 0.30) = 0.170 \text{ gallons}$$

Water left on person and room surfaces = 0.110 gallons

Total shower C.U. = 0.270 gpcd

The second method utilized measurements of water flow, temperature and relative humidity.

For a water conserving shower of 1.2 gpm and a measured initial relative humidity of 39 percent, the mass fraction of water evaporated was calculated as .0168 lb. water evaporated/lb. water input.

In an unvented shower, the measured final relative humidity was 89 percent having a final mass fraction ratio of .0097 lb. water evaporated/lb. water input.

For a vented system, a constant ratio of .0169 lb. water evaporated/lb. water input was determined.

The water splash was measured by weighing a towel dry and after wiping surfaces. Of this splash water, one third is attributed to condensation of evaporated water.

Calculations were also repeated for a (2.45 gpm) standard flow shower head.

Calculations were repeated for conditions of 8,700 feet elevation with typical January and July relative humidity values. It was concluded that the effect on the water depletion of the higher altitude would be negligible.

Using this method, typical calculations are as follows:

Low flow shower - unvented:

Mass fraction of water evaporated = $\frac{.0168 + .0097}{2}$ = 0.0133 lb water evap/lb water in

Water evaporated = .0133 lb/lb x 1.23 gal/min x 10 min = 0.1636 gal

Splash = 2/3 x 1.13 lb x $\frac{1 \text{ lb}}{8.342 \text{ gal}}$ = 0.0903 gal

Total Water Loss = 0.254 gal

Low flow shower - vented:

Water evaporated = .0169 lb/lb x 1.23 gal/min x 10 min = 0.2079 gal

Splash = 0.0903 gal

Total Water Loss = 0.298 gal

For a standard shower of 2.45 gpm the unvented condition has a loss of 0.372 gallons, and the vented condition has a loss of 0.504 gallons.

Combining values derived from both evaluation methods yields a C.U. loss range of 0.254 to 0.504 gallons/shower.

Dishwashing

Dishwashing losses were evaluated as the difference in mass between wet and dry dishes. A home dishwasher was carefully filled until the float valve solenoid was activated. The dishwasher with dried dishes was then filled to the proper level, the timer set forward, and the wastewater collected and measured. This was done for each cycle and cross-checked by allowing a completely automatic cycle with measured output. Most of the water evapoarted was lost during the drying cycle.

The C.U. was determined to be .024 to .051 gpcd.

Hand Washing

Hand wash water usage was studied. Towels were weighed to determine water held in fabric and splashing was noted. Water measured into and out of a basin supplemented estimates. About 2 percent of the water is evaporated or lost to spills which would give a range of 0.13 to 0.18 gpcd of C.U. due to handwashing.

Clothes Washing and Drying

In two different households a weeks laundry was weighed out of the washer and out of the dryer to establish the amount of water evaporated by the dryer. Clothes washers lose about 0.2 percent of the water used in a washing machine. The mass of water evaporated in the clothes dryer equals 48 to 62 percent of the dry weight of the clothes. An average load weighs 10 to 12 pounds, and dry clothes accumulate at a rate of 2 to 4 pounds per day per person. The C.U. range is from .128 gpcd to .325 gpcd loss of water.

Bath Water

Bath water use evaporates about 0.9 percent according to measured amounts input and output during a bath. Bath was not a use in this example, because all of the available water went to showers which has a higher C.U. A mixture of baths and showers will reduce the residential C.U.

Surface Cleaning

Surface cleaning water evaporates and spills about 8 to 9 percent of the water used. Measurements of the volume of water in a dish pan before and after cleaning was used to confirm the amount of loss, which is mostly the water held in the cleaning sponge.

Miscellaneous Losses

Cooking water evaporates 5 to 6 percent of water used in a kitchen with a modern microwave. This does not include water which becomes part of the food.

Coffee pots lose 3 to 4 percent to evaporation.

Floor scrubbing loses 15 to 18 percent when a large spaghetti mop is used. A sponge mop will lose about 10 to 13 percent.

Human consumption augments the waste water by 0.213 gpcd, assuming about one-half the fluids are imported and a diet of about 2000 calories.

An additional loss is the increase in humidity in the sewer vent. Assume 50 gpcd displaces 30 percent relative humidity air.

$$50 \text{ gal.} = 6.684 \text{ c.f.}$$

$$6.684 \text{ c.f.} \times 0.7 \times .000138 \text{ gal/c.f. dry air} = .0006 \text{ gpcd}$$

$$\text{and } 75 \text{ gal.} = .0010 \text{ gpcd.}$$

Other minor losses range from 0.058 to 0.060 gpcd and include room humidifier, hot tubs, plant and pet watering, carpet cleaning and spills not covered above.

The residential C.U. loss is summarized in Table 5.

TABLE 5

RESIDENTIAL CONSUMPTIVE USE

Item	50 gpcd (least)	75 gpcd (most)
Water Closet	.0069	.0136
Hand Wash	0.1330	0.1800
Shower	.248	.504
Clothes Washer	.128	.325
Dish Washer	.024	.051
Surface Cleaning	0.044	0.054
Cooking	0.015	0.160
Human Consumption	0.*	0.*
Coffee	0.003	0.005
Floor Scrubbing	0.006	0.009
Disposal	0.001	0.002
Other Minor Losses	0.058	0.060
Sewer Venting	0.0006	0.0010
Total C.U.	0.6675	1.3646
Total Water Use	50.00 gpcd	75.00 gpcd

* Human consumption results in a credit of 0.213 gpcd and is not included.

The augmentation from human metabolism and imported fluids amounts to a credit of 0.213 gpcd. This credit reduces the C.U. to 0.455 gpcd for a 50 gpcd use and 1.152 gpcd for a 75 gpcd use.

Based on interviews with a local building department official, a heating and plumbing contractor and an accommodation reservation agency, it was determined that new multi-family residential construction in the Regis-Maryvale area will not include humidifiers.

To keep a reasonable balance within the 50 to 75 gpcd use range, excessive water use in one category must result in very low water use in other categories. An increase in the number of showers and time in the shower, pounds of clothes washed and number of hand washes, increases C.U. Increased use of the water closet and disposal will lower consumptive uses.

Water use determinations constrained by balancing uses within the 50 to 75 gpcd range allows an estimate of C.U. ranging between 0.455 gpcd (including augmentation from metabolism) to 1.365 gpcd without metabolism.

WASTEWATER CONSUMPTIVE USE DETERMINATION

The second aspect of residential consumptive use is the loss that occurs during the wastewater treatment process. Water is lost to vapor due to cooling of the effluent and from evaporation by diffusion into the air. The current wastewater treatment plant has a 1.0 mgd capacity with capacity to treat 1,120 acre-feet per year to secondary standards. The water surface area is approximately 4 acres. Cooling losses are calculated based on wastewater treatment plant influent and effluent temperatures. Net evaporation is calculated as the difference of Grand Lake pan evaporation minus precipitation multiplied by .70 pan coefficient.

In the winter months of November to April the average sewage influent temperature is 36°F. The average air temperature is 18°F. After detention time in the ponds the sewage effluent has cooled to reach the same temperature as the receiving stream, the Fraser River. The sum of cooling and net evaporation losses is 0.14 acre-feet for these six months.

The average influent temperature for the summer months of May to October is 62°F. The average air temperature is 46°F, and the final pond temperature is 46°F. The cooling loss is 8.43 acre-feet and the net evaporation loss is 6.54 acre-feet. The sum is 14.97 acre-feet.

The annual loss is 15.11 acre-feet or 1.35 percent of treated wastewater. At the 50 gpcd rate 1.35 percent is 0.675 gpcd and at 75 gpcd is 1.0125 gpcd. This estimate is conservative because all cooling is attributed to evaporation with no heat loss assummed due to radiation, conduction or convection.

CONCLUSIONS

In conclusion, the residential C.U. of water ranges from 0.455 gpcd to 1.365 gpcd. The C.U. from the wastewater plant to river is 0.675 gpcd to 1.0125 gpcd. The total in-house consumptive use of water ranges from 1.130 to 2.378 gpcd.

Submitted by,

By Patricia K. Flood
Patricia K. Flood, P.E.

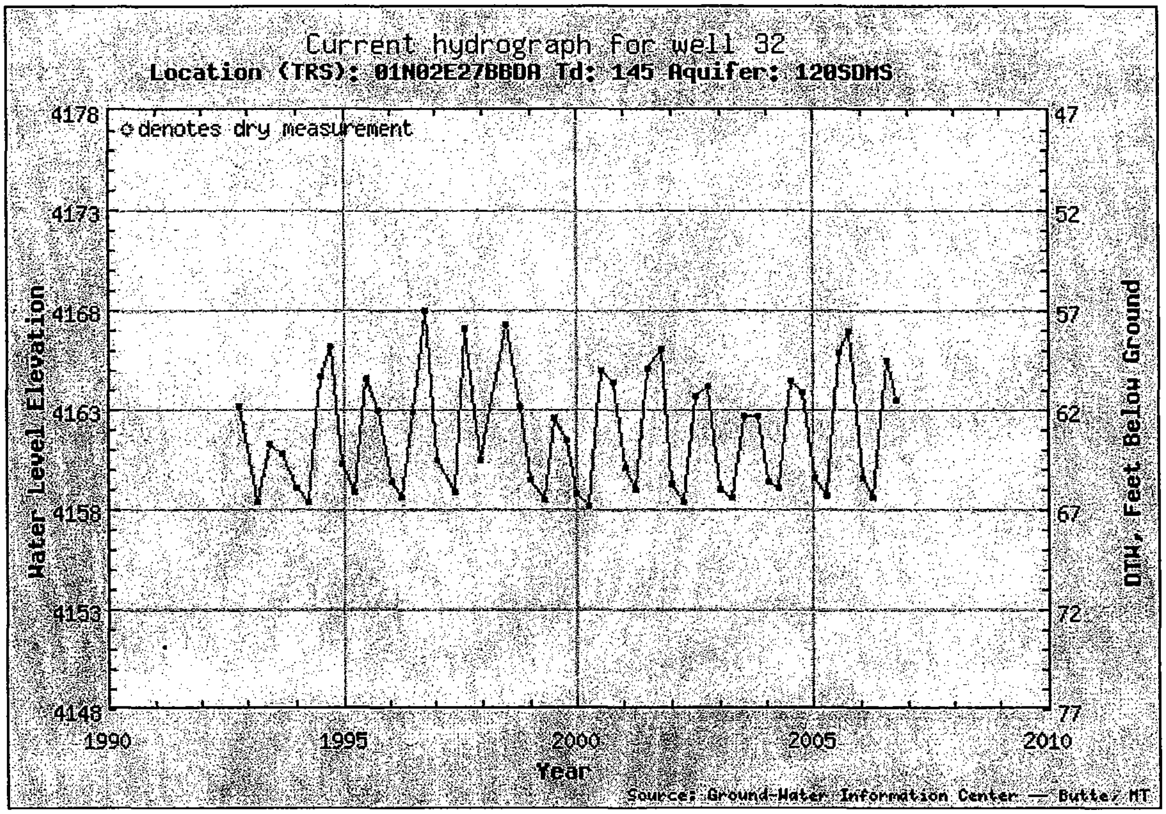
By Dwight L. Kimsey
Dwight L. Kimsey

(REGIS.15)
DWK/PKF:klr
831-029.030

Attachment D

Montana Bureau of Mines and Geology Statewide Monitoring Network

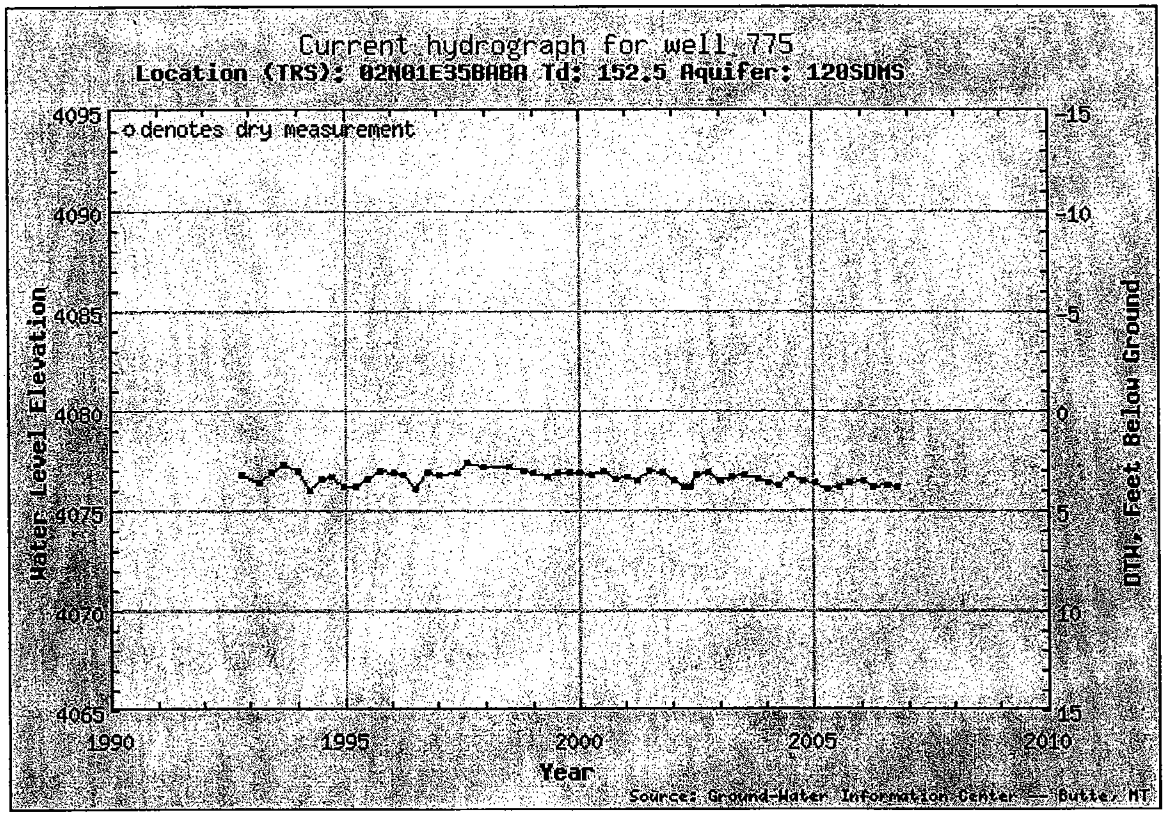
Ground-water Levels for Monitoring Wells in Gallatin County



GWIC Id: 32
Site Name: WILLIAMS CHUCK AND ROBERTA
Location: 01N02E27BBDA
Total Depth: 145 feet
Number of Measurements: 54
Period of Record: 10/30/1992 1:29:00 PM - 10/5/2006 8:51:00 AM

Ground-Water Infomation Center Well Hydrograph

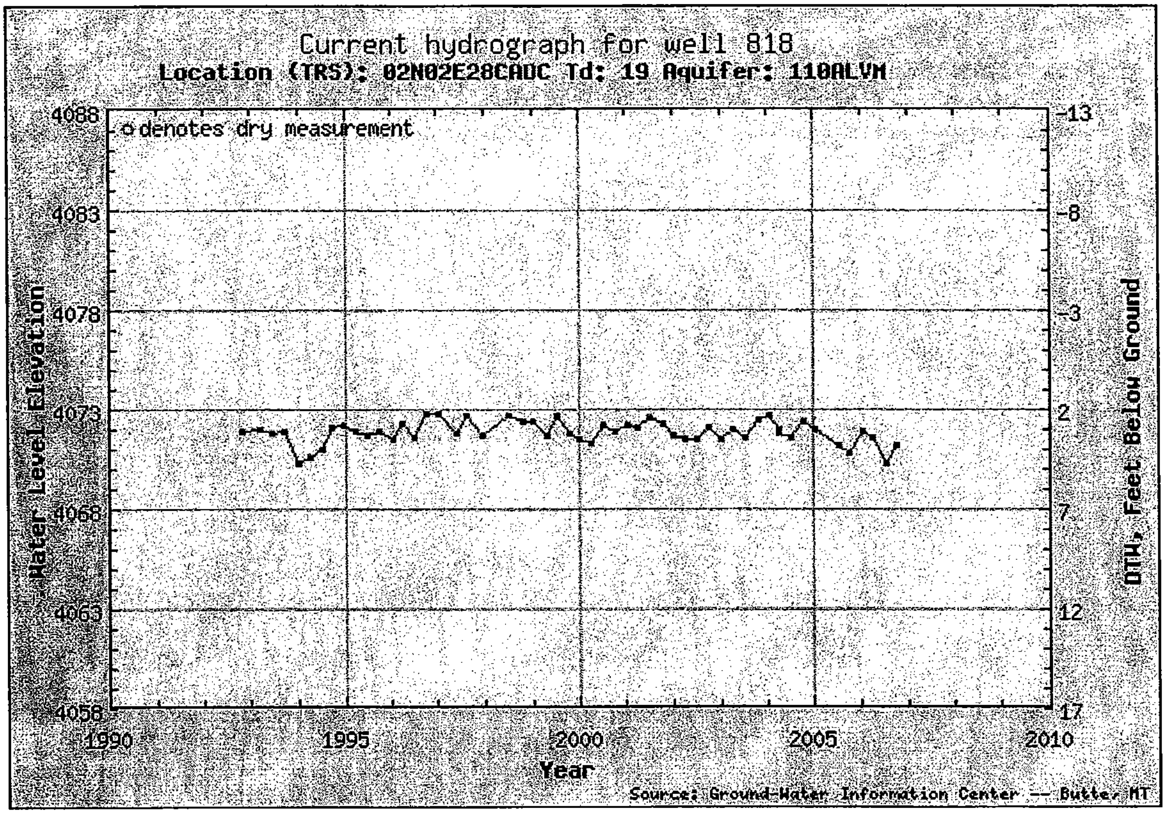
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 775
Site Name: DELAITTRE DENNIS
Location: 02N01E35BABA
Total Depth: 152.5 feet
Number of Measurements: 55
Period of Record: 10/27/1992 9:59:00 AM - 10/4/2006 2:50:00 PM

Ground-Water Infomation Center Well Hydrograph

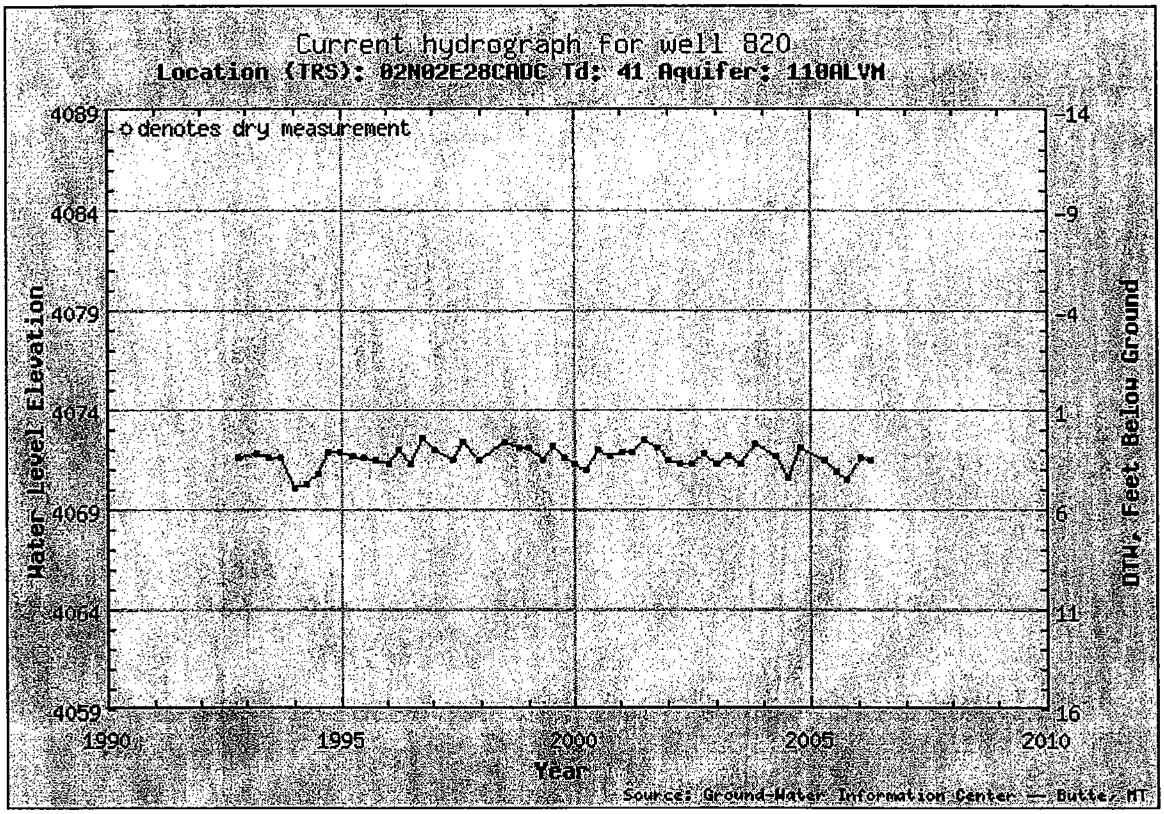
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 818
Site Name: MBMG RESEARCH WELL 1 * HEPNER
Location: 02N02E28CADC
Total Depth: 19 feet
Number of Measurements: 54
Period of Record: 10/27/1992 10:43:00 AM - 10/4/2006 4:18:00 PM

Ground-Water Infomation Center Well Hydrograph

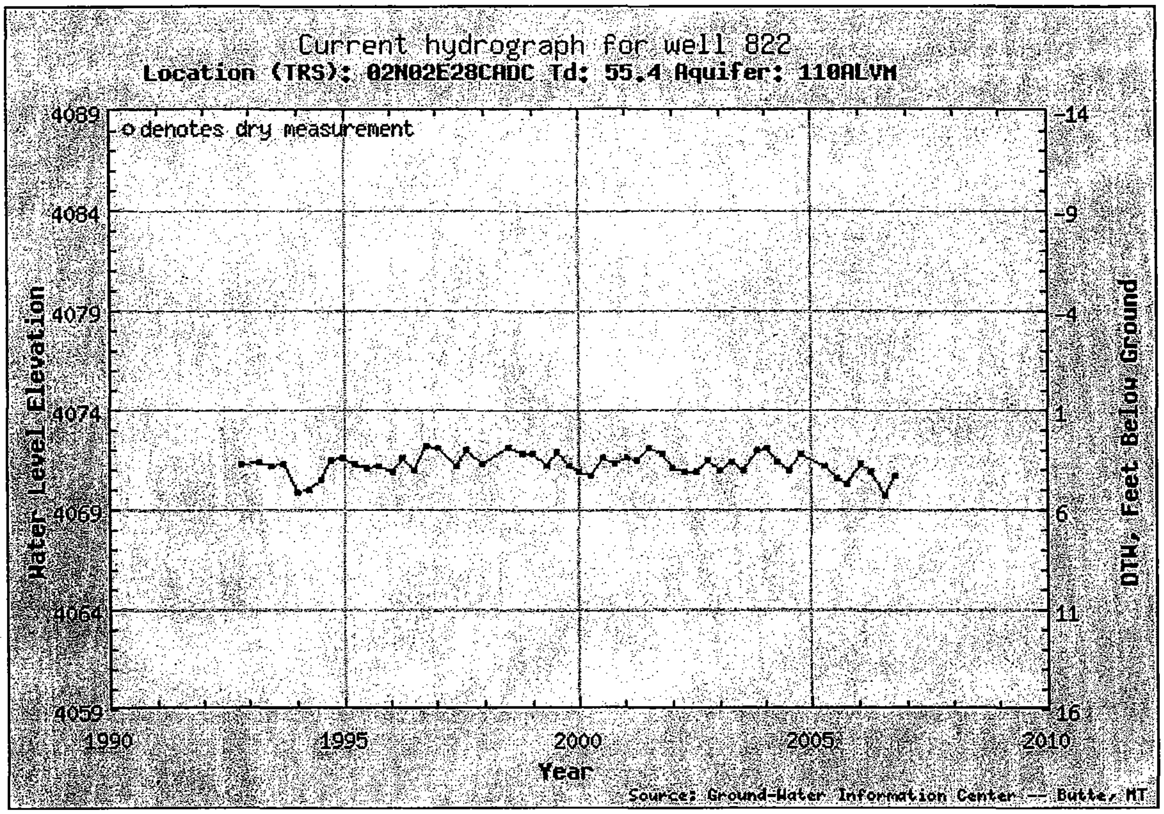
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 820
Site Name: MBMG RESEARCH WELL 2 * HEPNER
Location: 02N02E28CADC
Total Depth: 41 feet
Number of Measurements: 50
Period of Record: 10/27/1992 11:00:00 AM - 4/6/2006 9:57:00 AM

Ground-Water Infomation Center Well Hydrograph

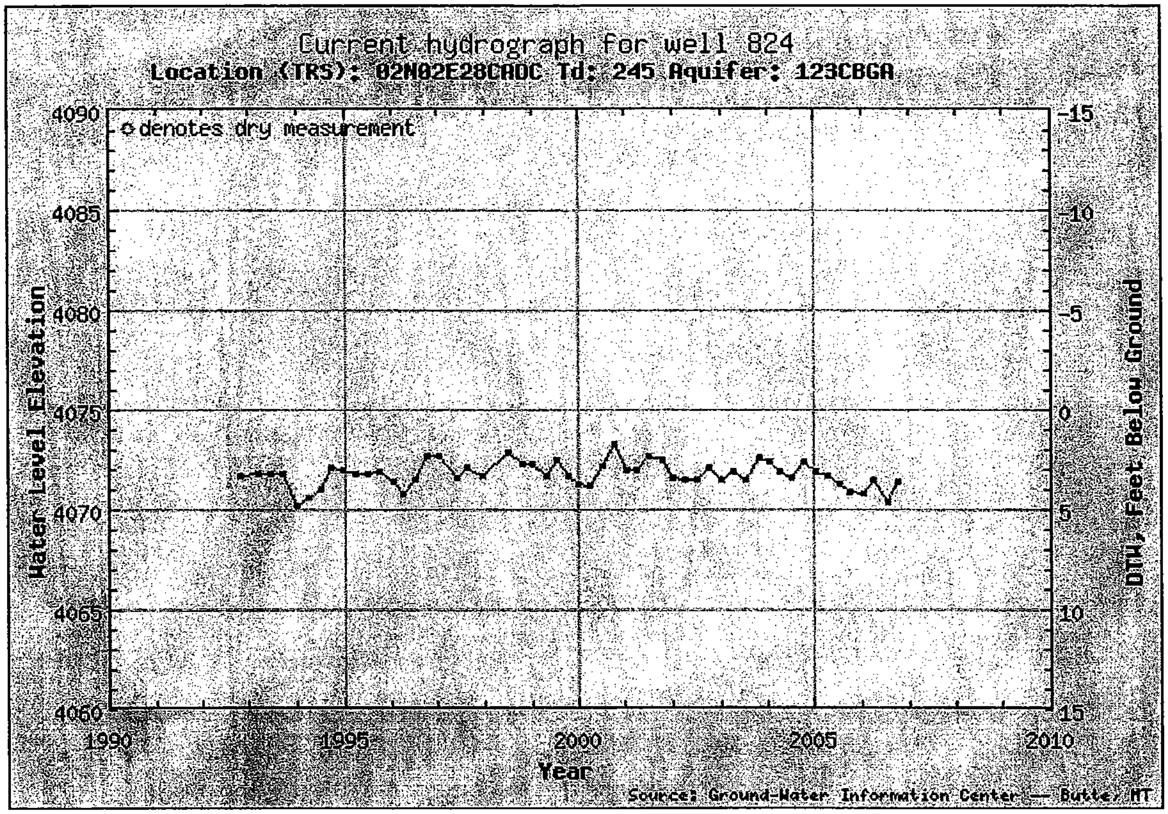
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 822
Site Name: MBMG RESEARCH WELL 3 * HEPNER
Location: 02N02E28CADC
Total Depth: 55.4 feet
Number of Measurements: 53
Period of Record: 10/27/1992 11:06:00 AM - 10/4/2006 4:16:00 PM

Ground-Water Infomation Center Well Hydrograph

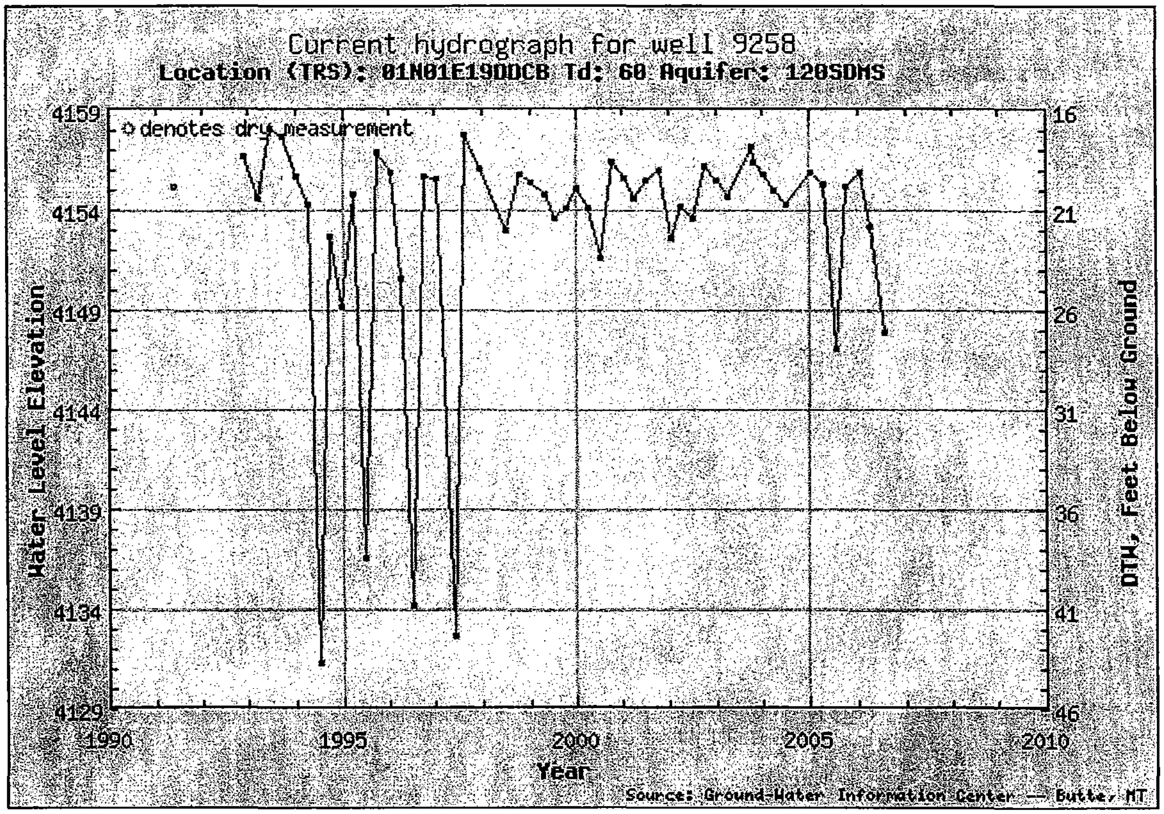
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 824
Site Name: MBMG RESEARCH WELL 4 * HEPNER
Location: 02N02E28CADC
Total Depth: 245 feet
Number of Measurements: 54
Period of Record: 10/27/1992 10:38:00 AM - 10/4/2006 4:14:00 PM

Ground-Water Infomation Center Well Hydrograph

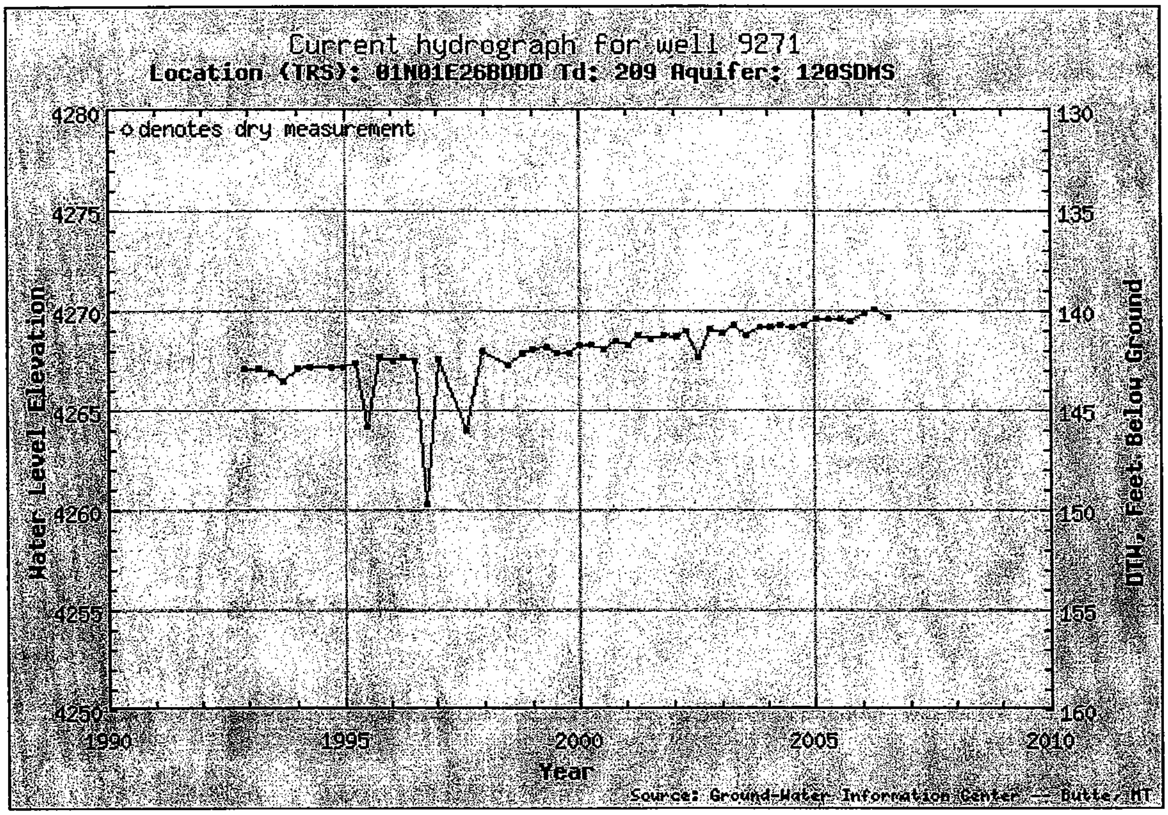
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 9258
Site Name: COOPER JACK
Location: 01N01E19DDCB
Total Depth: 60 feet
Number of Measurements: 53
Period of Record: 5/29/1991 - 7/19/2006 3:56:00 PM

Ground-Water Infomation Center Well Hydrograph

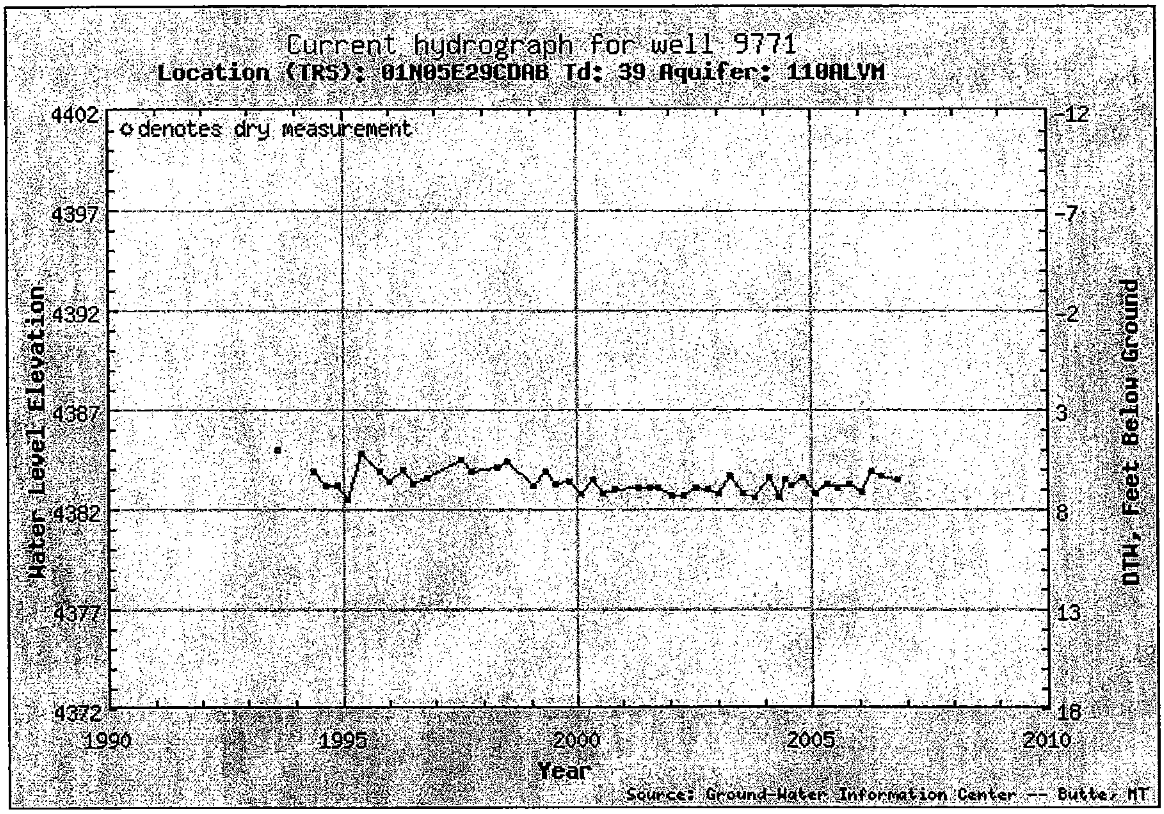
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 9271
Site Name: LANE BROTHERS
Location: 01N01E26BDDD
Total Depth: 209 feet
Number of Measurements: 51
Period of Record: 11/20/1992 2:10:00 PM - 7/20/2006 9:02:00 AM

Ground-Water Infomation Center Well Hydrograph

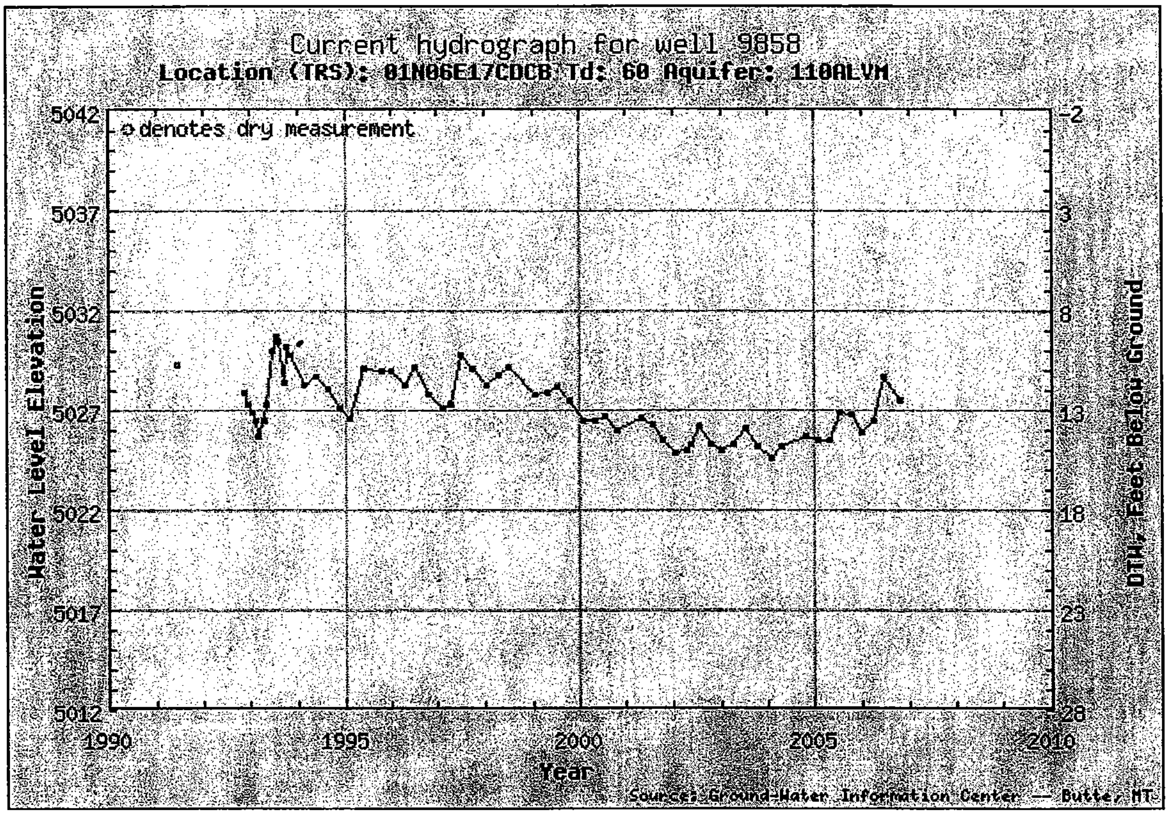
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 9771
Site Name: THOMPSON ALVIN
Location: 01N05E29CDAB
Total Depth: 39 feet
Number of Measurements: 47
Period of Record: 8/7/1993 4:28:00 PM - 10/21/2006 3:10:00 PM

Ground-Water Infomation Center Well Hydrograph

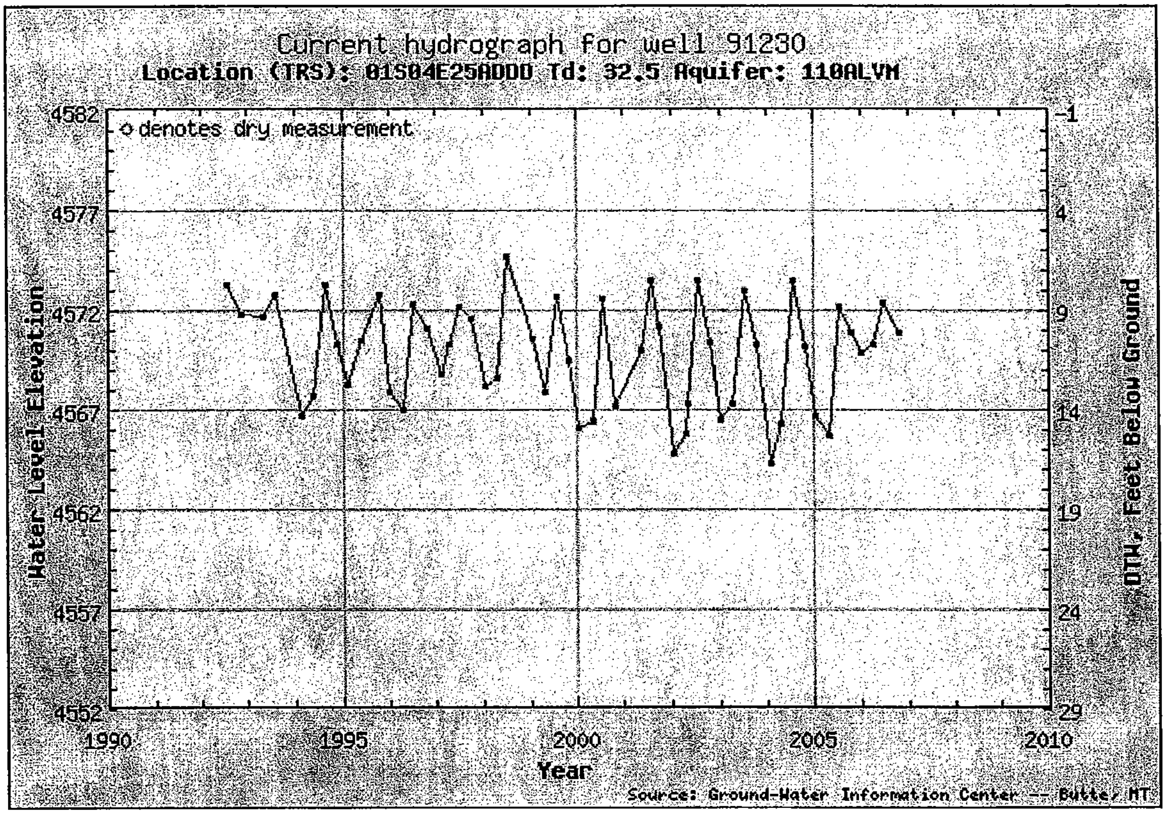
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 9858
Site Name: MADDEN JIM AND CORRINE
Location: 01N06E17CDCB
Total Depth: 60 feet
Number of Measurements: 63
Period of Record: 6/20/1991 - 10/21/2006 4:12:00 PM

Ground-Water Infomation Center Well Hydrograph

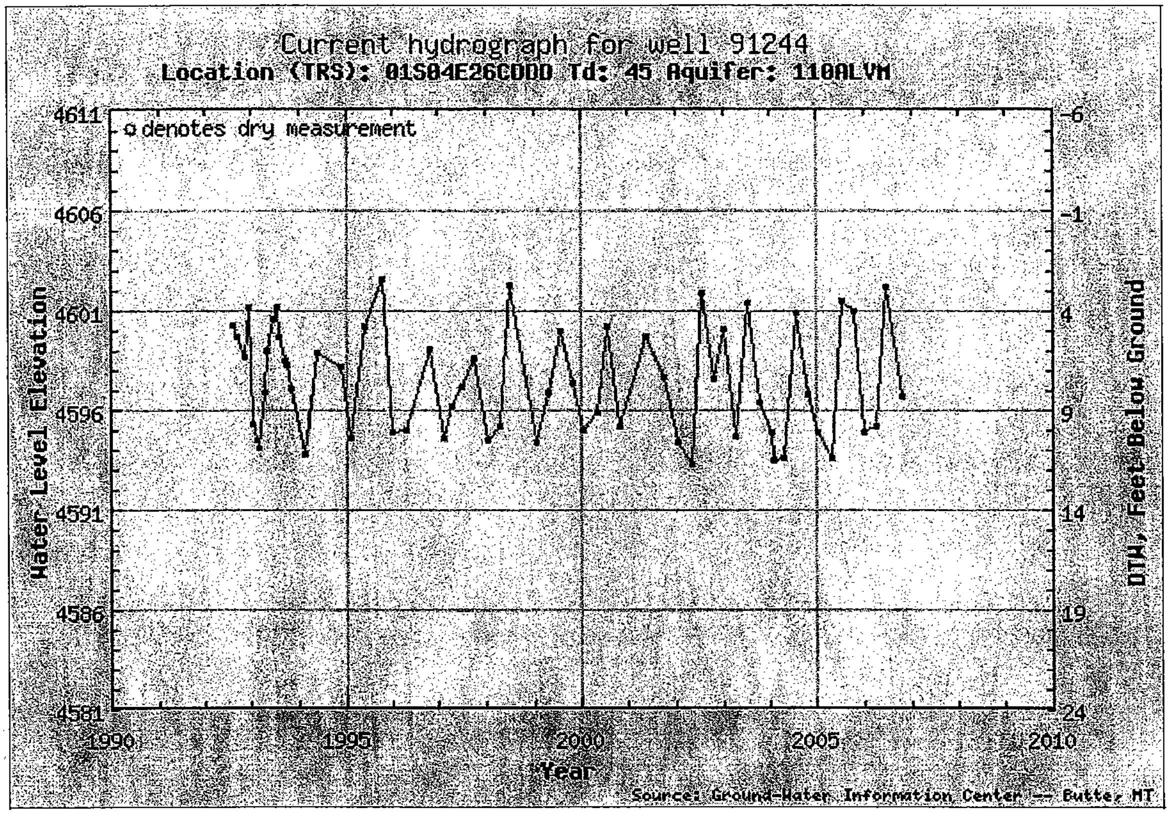
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 91230
Site Name: MARX DON
Location: 01S04E25ADDD
Total Depth: 32.5 feet
Number of Measurements: 54
Period of Record: 7/29/1992 - 10/22/2006 10:40:00 AM

Ground-Water Infomation Center Well Hydrograph

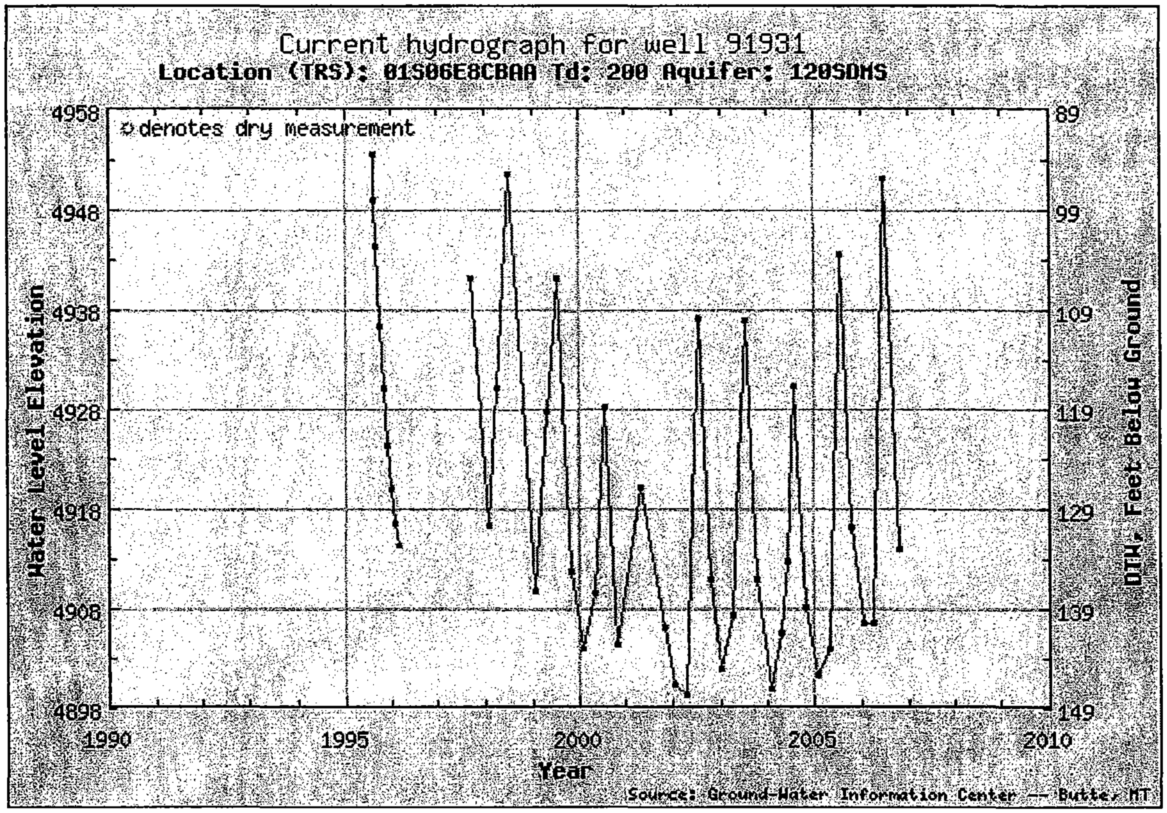
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 91244
Site Name: SIEVERT JACK
Location: 01S04E26CDDD
Total Depth: 45 feet
Number of Measurements: 62
Period of Record: 7/30/1992 - 10/22/2006 1:39:00 PM
Get the data used to make this chart

Ground-Water Infomation Center Well Hydrograph

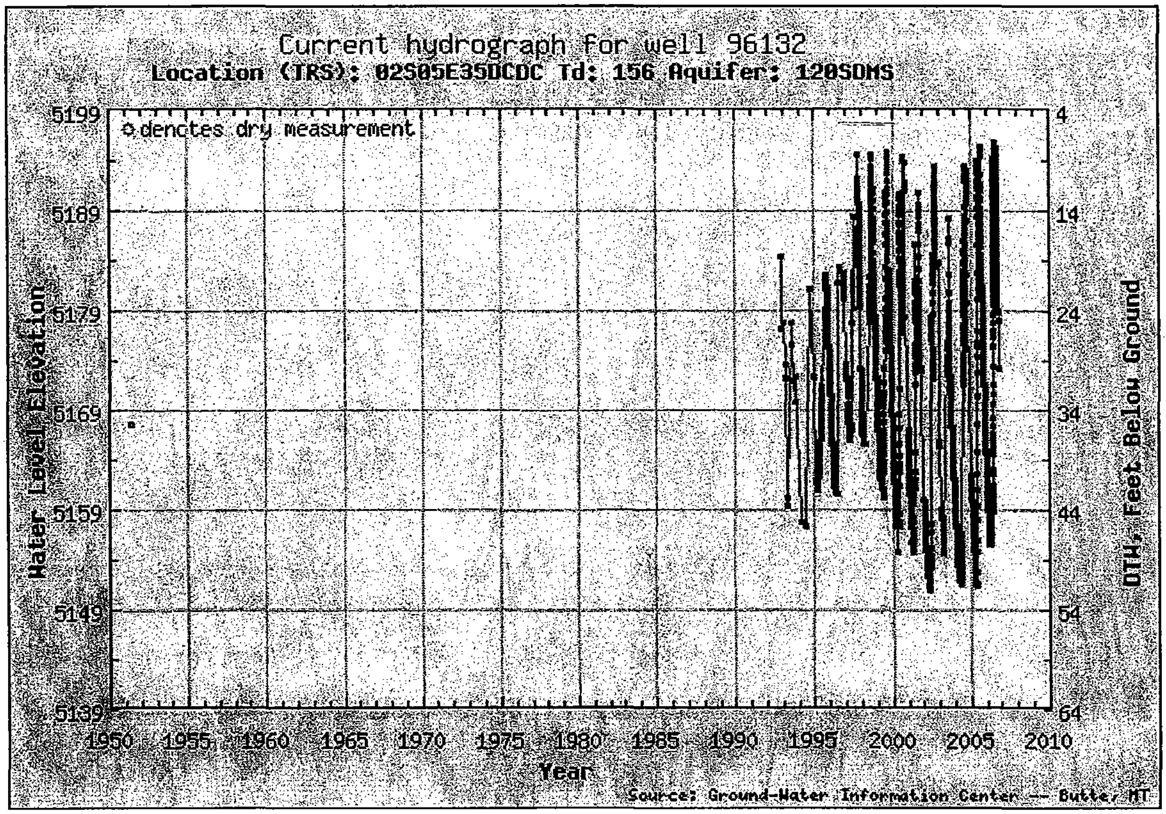
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 91931
Site Name: RUSOFF ANNE
Location: 01S06E8CBAA
Total Depth: 200 feet
Number of Measurements: 44
Period of Record: 8/8/1995 3:05:00 PM - 10/21/2006 3:45:00 PM

Ground-Water Infomation Center Well Hydrograph

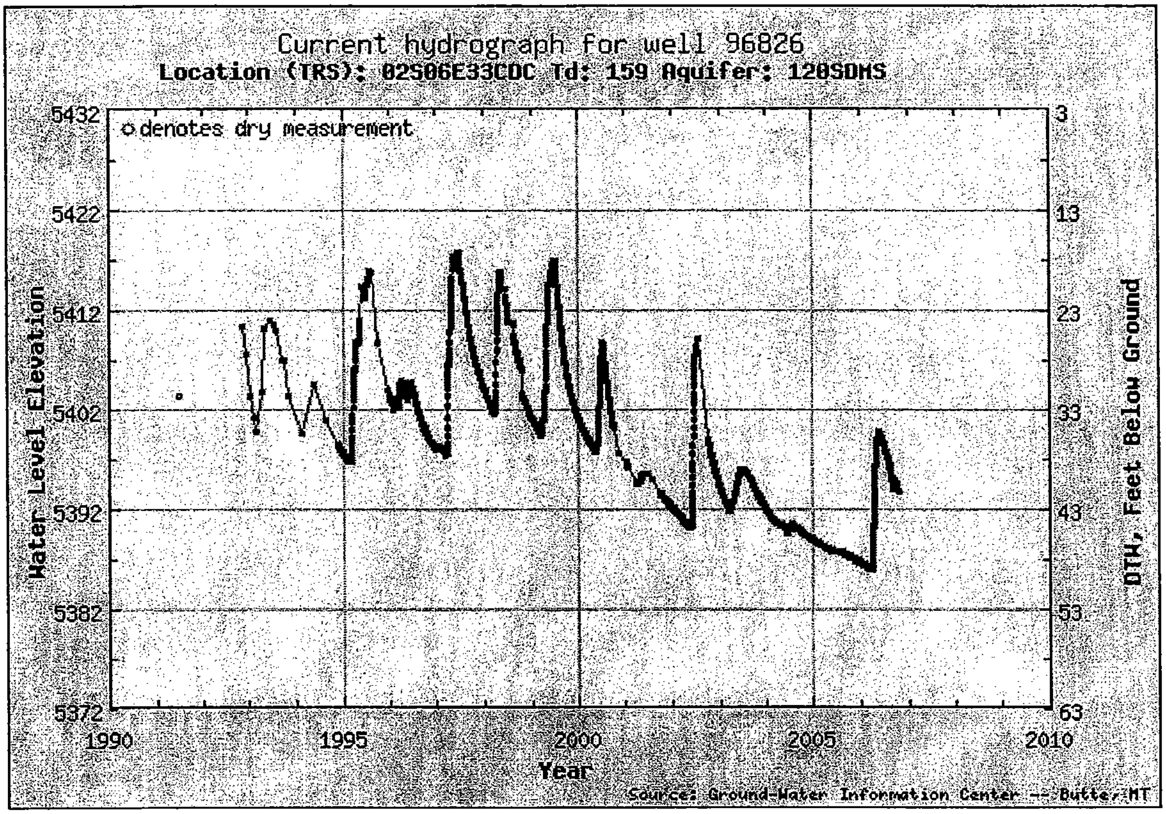
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 96132
Site Name: LAPLANT DON
Location: 02S05E35DCDC
Total Depth: 156 feet
Number of Measurements: 11369
Period of Record: 5/14/1951 - 10/22/2006 8:41:00 AM

Ground-Water Infomation Center Well Hydrograph

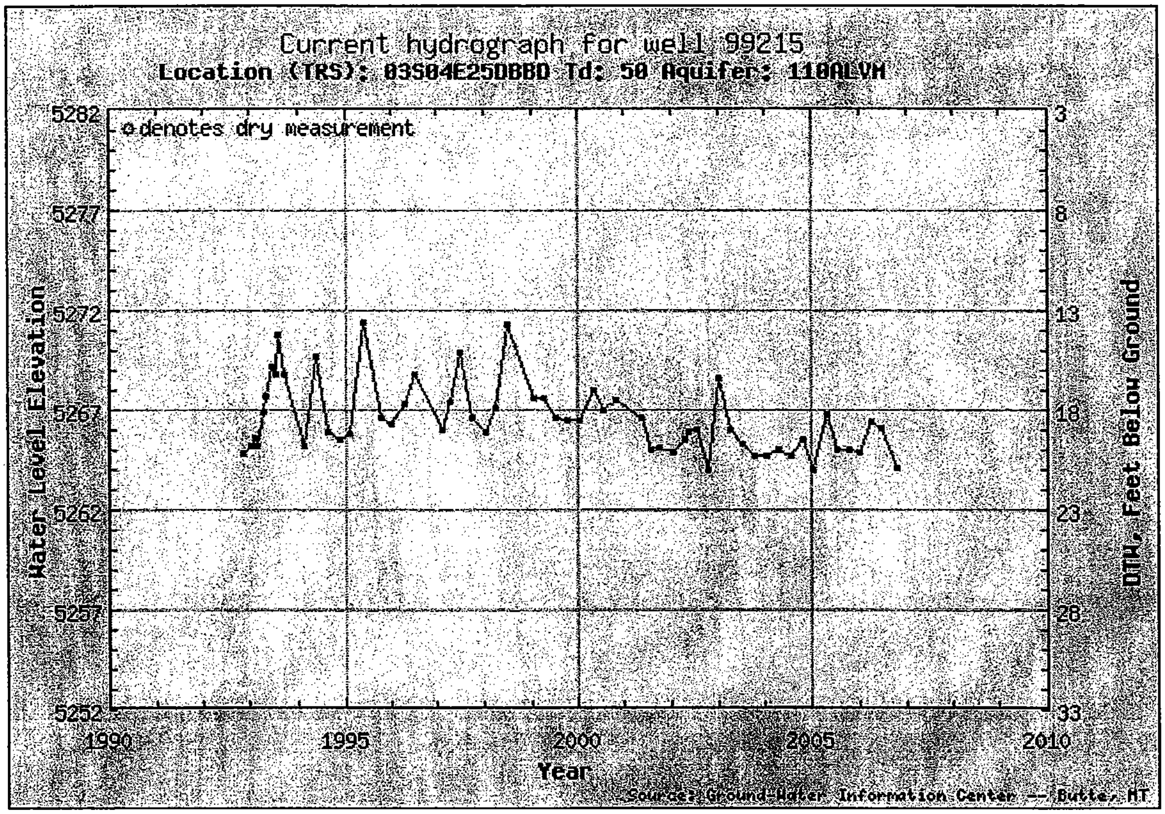
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 96826
Site Name: EAGLE ROCK RANCH *WELL 1
Location: 02S06E33CDC
Total Depth: 159 feet
Number of Measurements: 12085
Period of Record: 6/22/1991 - 10/21/2006 7:50:00 AM

Ground-Water Infomation Center Well Hydrograph

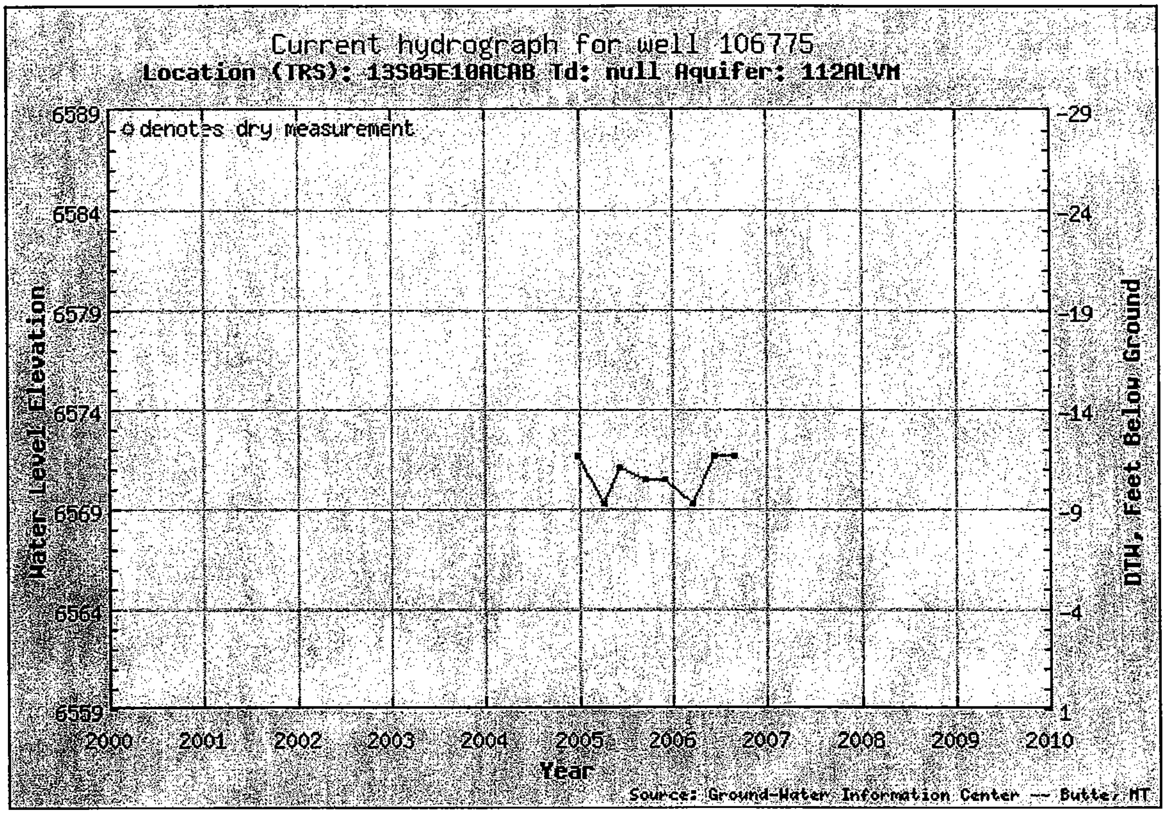
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 99215
Site Name: HUTTINGA JELKE
Location: 03S04E25DBBD
Total Depth: 50 feet
Number of Measurements: 60
Period of Record: 6/18/1991 - 10/22/2006 9:15:00 AM

Ground-Water Infomation Center Well Hydrograph

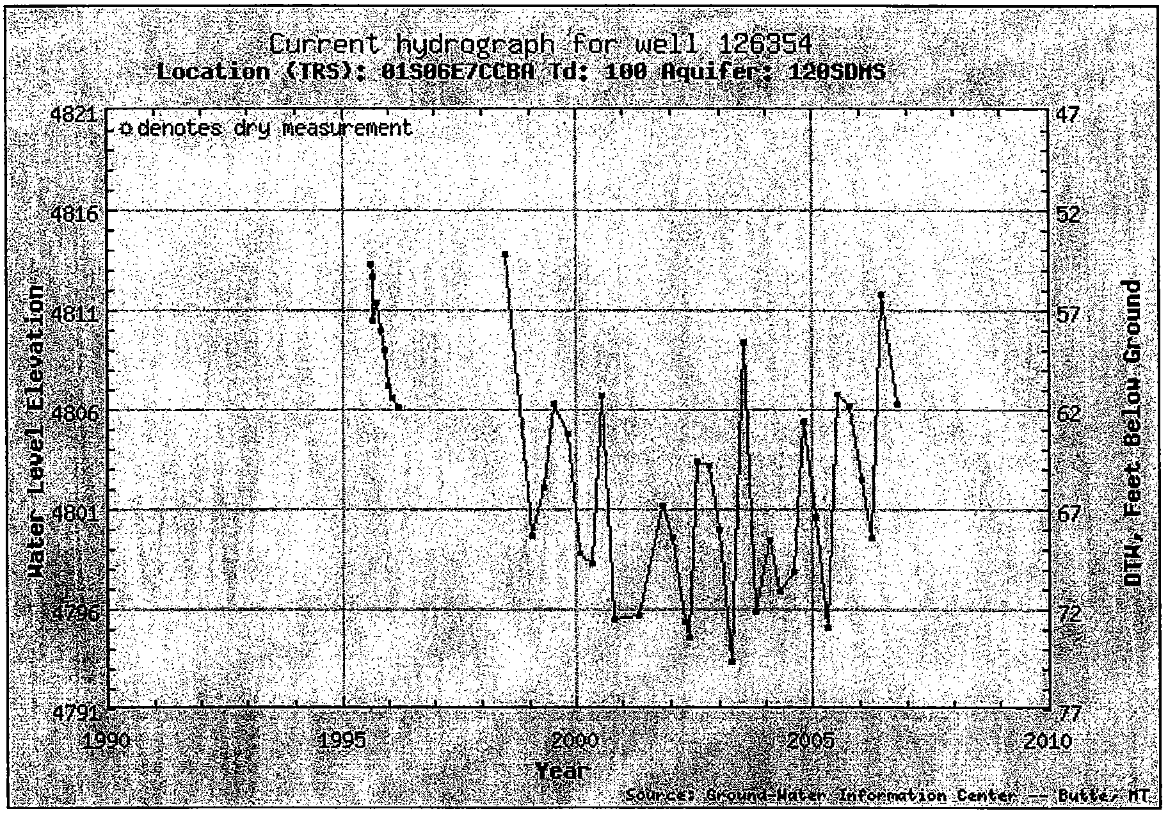
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 106775
Site Name: U S FOREST SERVICE * BAKER HOLE CAMP
Location: 13S05E10ACAB
Total Depth: feet
Number of Measurements: 8
Period of Record: 12/20/2004 11:04:00 AM - 9/1/2006 4:55:00 PM

Ground-Water Infomation Center Well Hydrograph

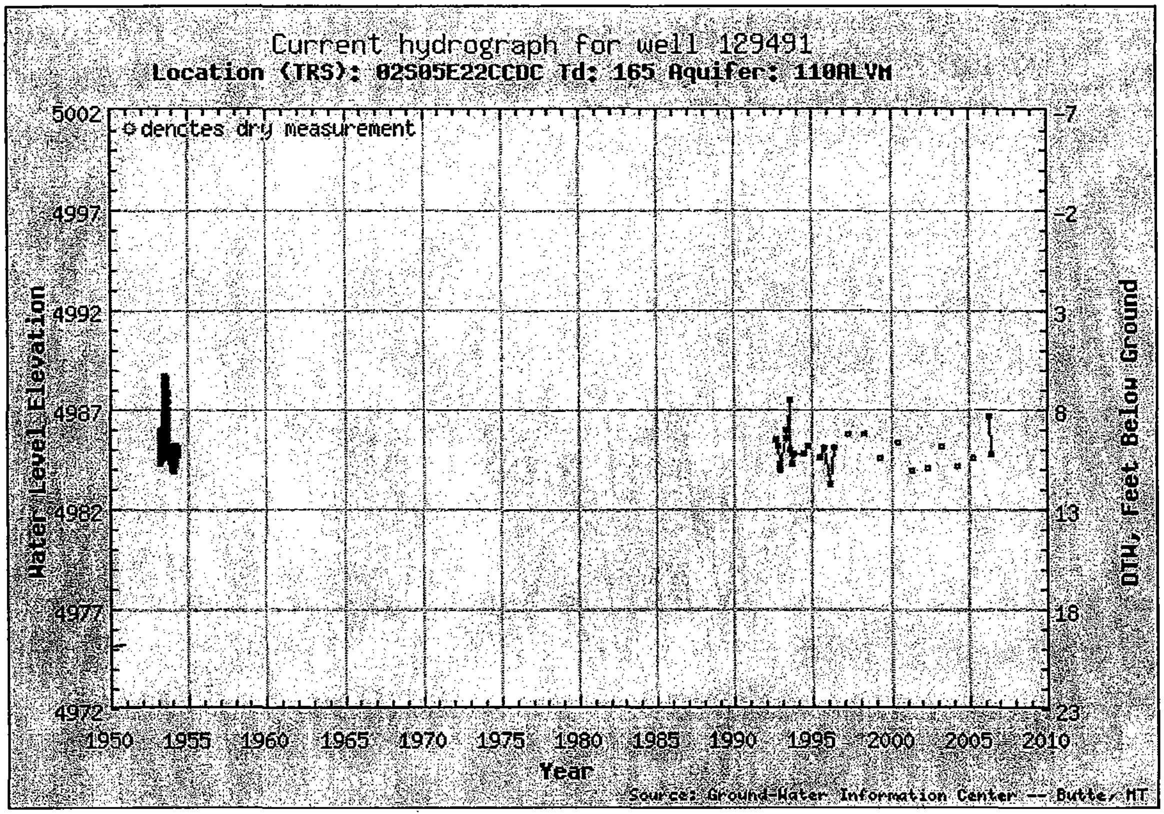
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 126354
Site Name: WISEMAN KENNY AND WENDY
Location: 01S06E7CCBA
Total Depth: 100 feet
Number of Measurements: 41
Period of Record: 8/9/1995 3:30:00 PM - 10/21/2006 3:35:00 PM

Ground-Water Infomation Center Well Hydrograph

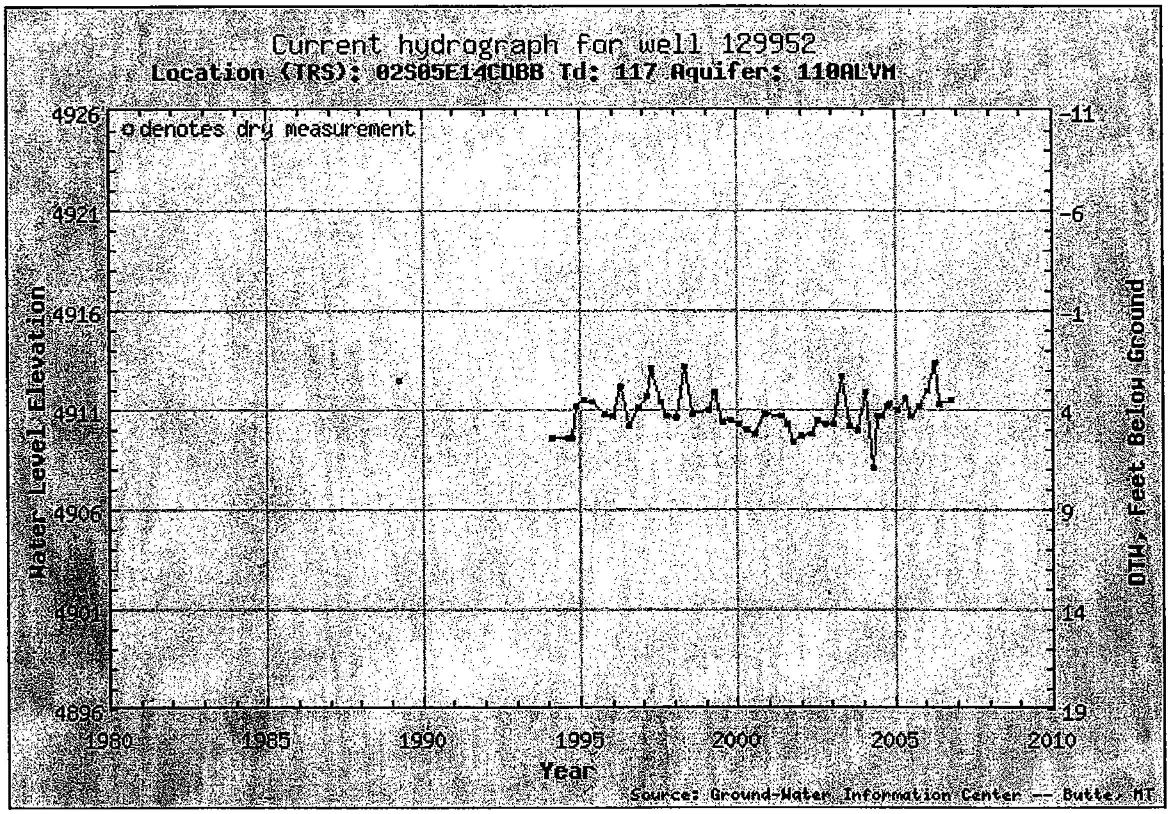
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 129491
Site Name: USGS * HALL H R
Location: 02S05E22CCDC
Total Depth: 165 feet
Number of Measurements: 421
Period of Record: 3/9/1953 - 5/22/2006 2:19:00 PM

Ground-Water Infomation Center Well Hydrograph

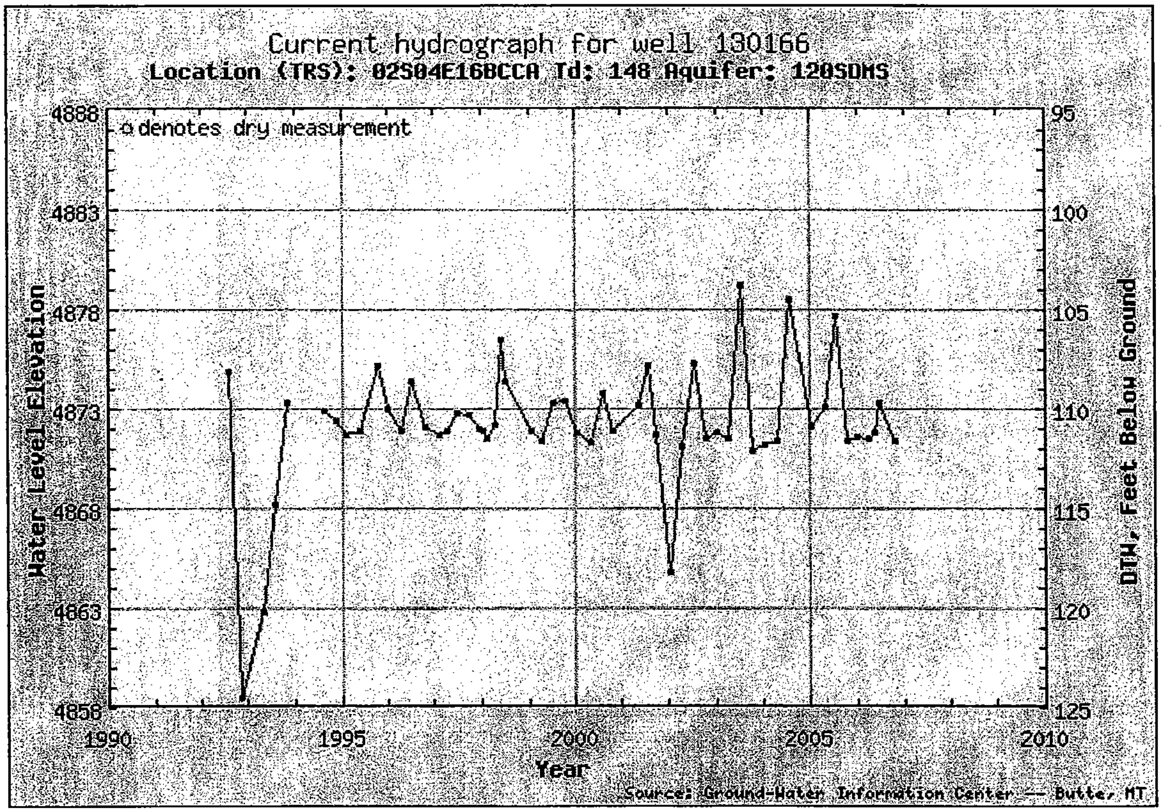
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 129952
Site Name: MONTANA STATE UNIVERSITY STUCKY
Location: 02S05E14CDBB
Total Depth: 117 feet
Number of Measurements: 52
Period of Record: 4/7/1989 - 10/22/2006 11:15:00 AM

Ground-Water Infomation Center Well Hydrograph

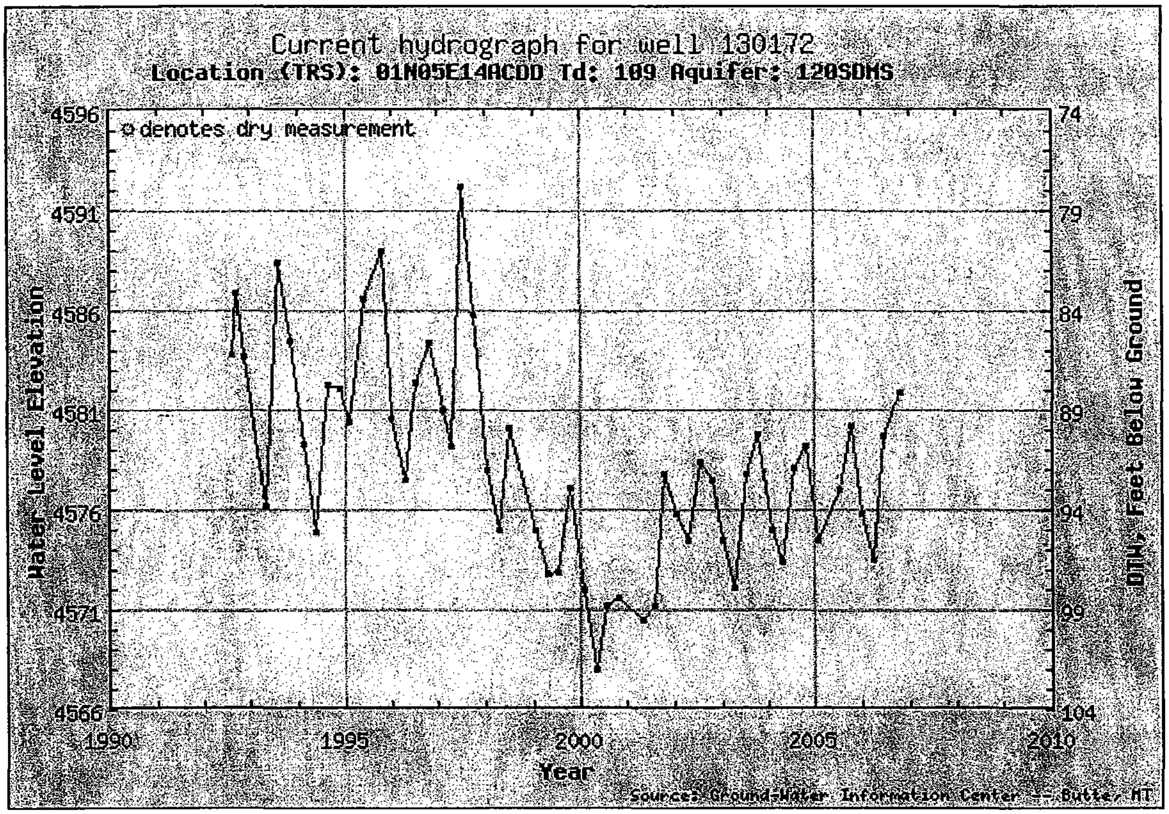
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 130166
Site Name: BRYAN RICHARD
Location: 02S04E16BCCA
Total Depth: 148 feet
Number of Measurements: 55
Period of Record: 8/11/1992 - 10/20/2006 10:25:00 AM

Ground-Water Infomation Center Well Hydrograph

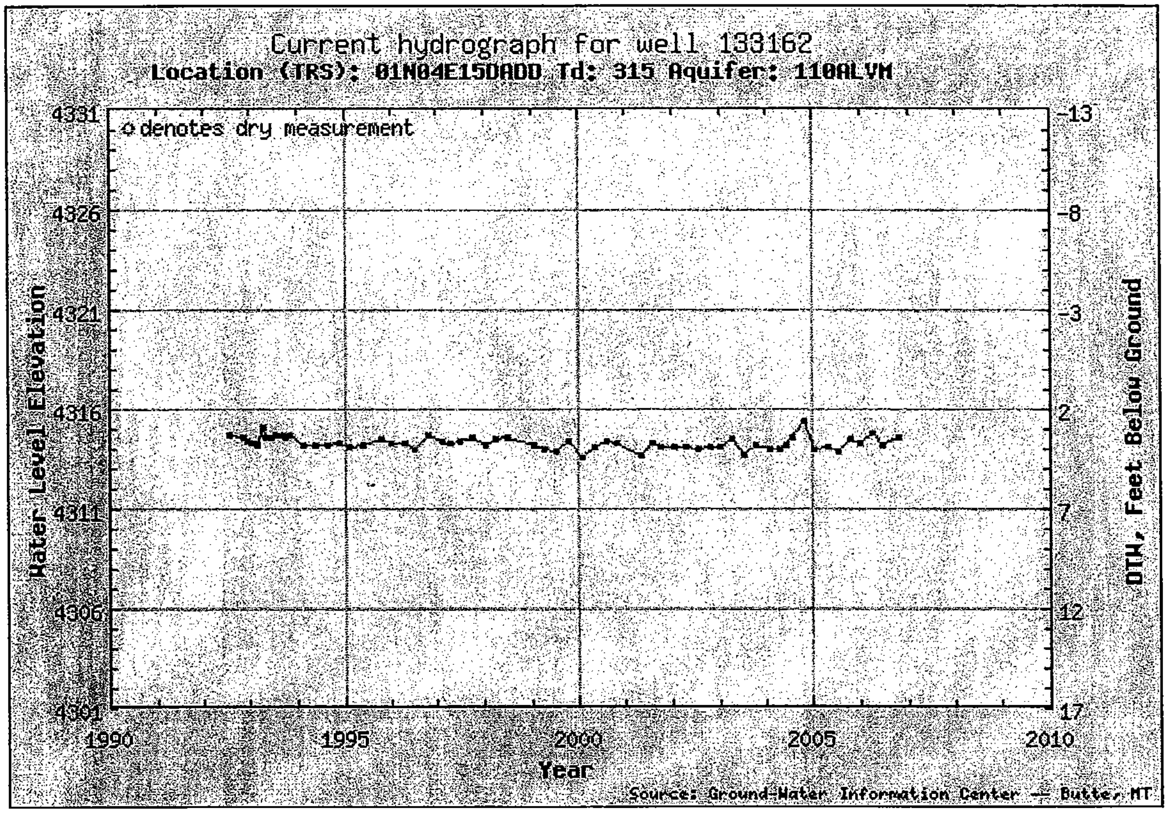
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 130172
Site Name: BROWN RICHARD
Location: 01N05E14ACDD
Total Depth: 109 feet
Number of Measurements: 54
Period of Record: 7/31/1992 - 10/21/2006 4:00:00 PM

Ground-Water Infomation Center Well Hydrograph

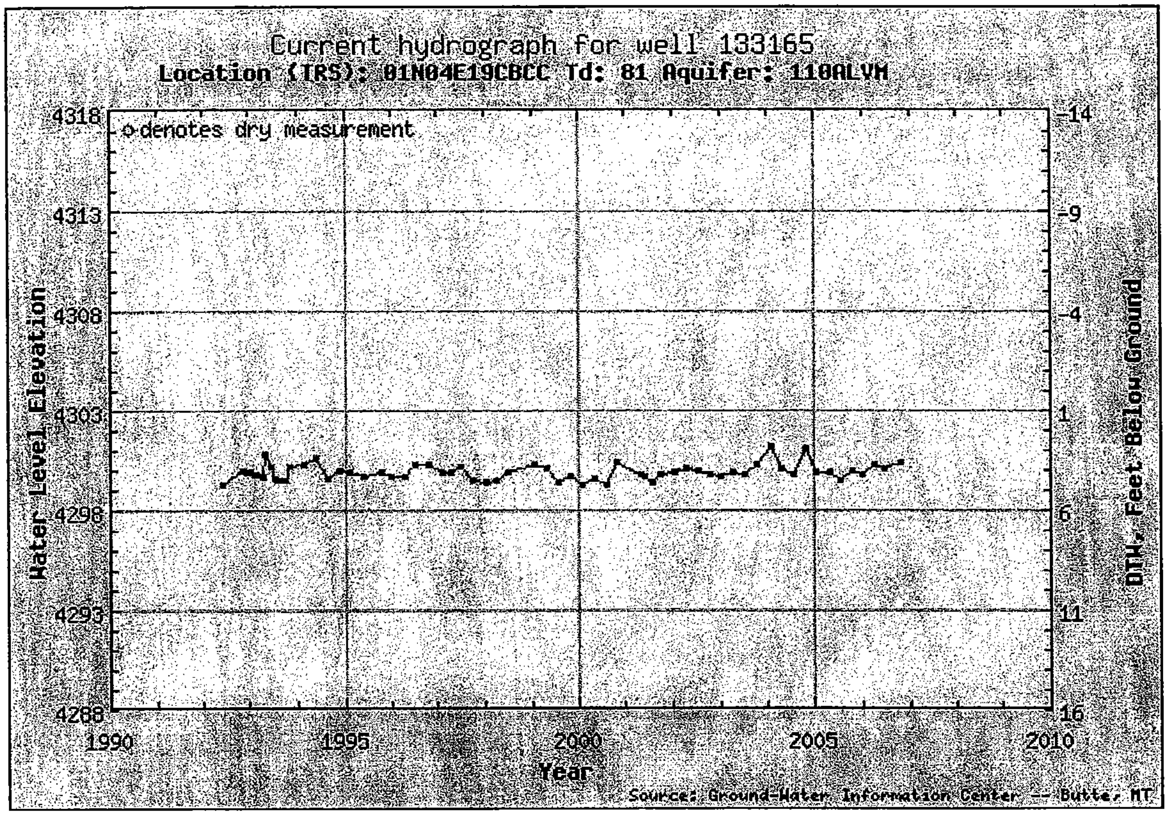
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 133162
Site Name: USGS OBSERVATION WELL RICHARD MORGAN
Location: 01N04E15DADD
Total Depth: 315 feet
Number of Measurements: 64
Period of Record: 7/14/1992 - 10/21/2006 5:19:00 PM

Ground-Water Infomation Center Well Hydrograph

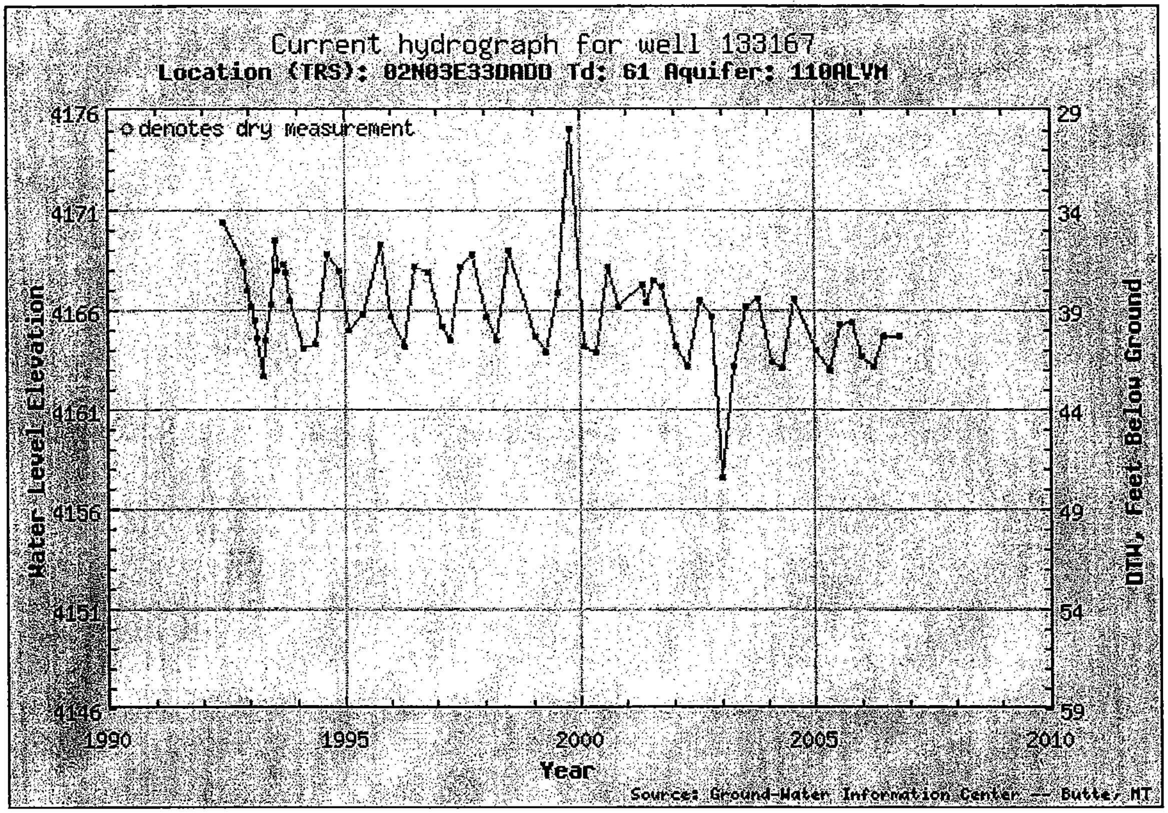
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 133165
Site Name: USGS OBSERVATION WELL HEEB ROAD
Location: 01N04E19CBCC
Total Depth: 81 feet
Number of Measurements: 64
Period of Record: 6/11/1992 - 10/21/2006 6:23:00 PM

Ground-Water Infomation Center Well Hydrograph

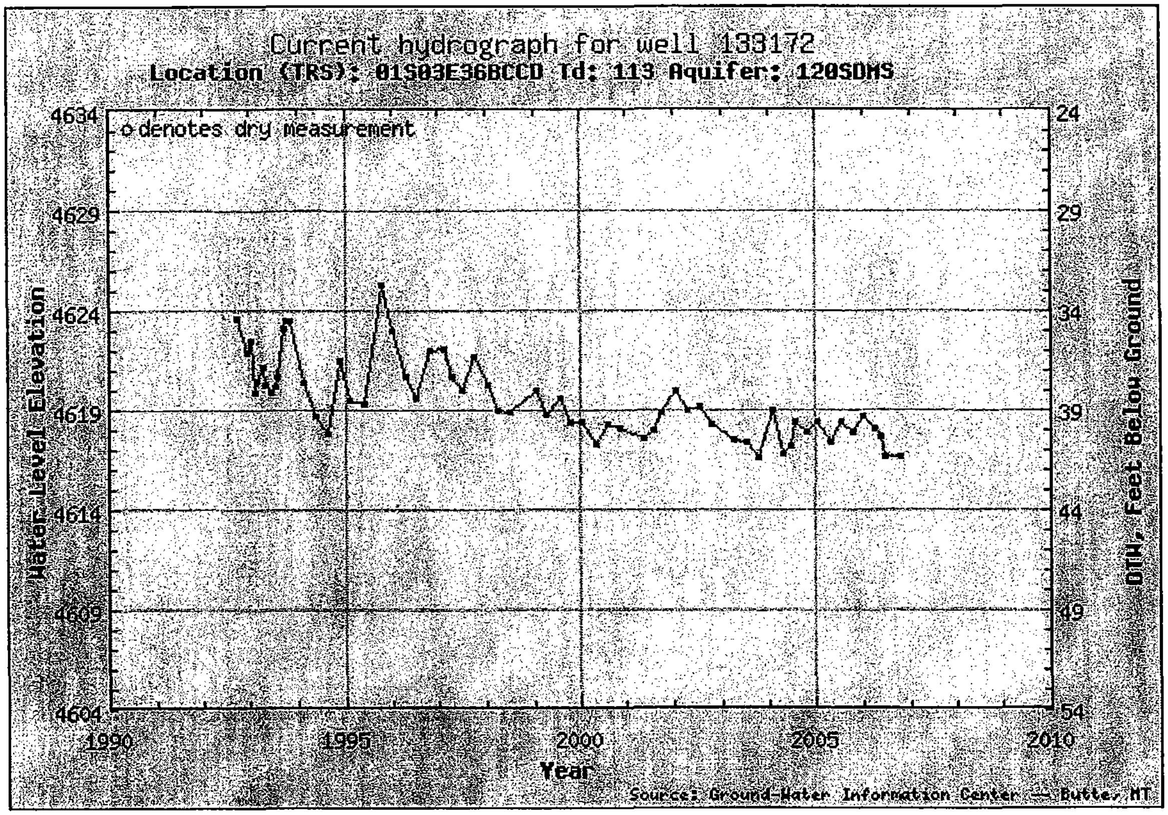
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 133167
Site Name: USGS OBSERVATION WELL - RIECHMAN
Location: 02N03E33DADD
Total Depth: 61 feet
Number of Measurements: 63
Period of Record: 6/9/1992 - 10/21/2006 5:45:00 PM

Ground-Water Infomation Center Well Hydrograph

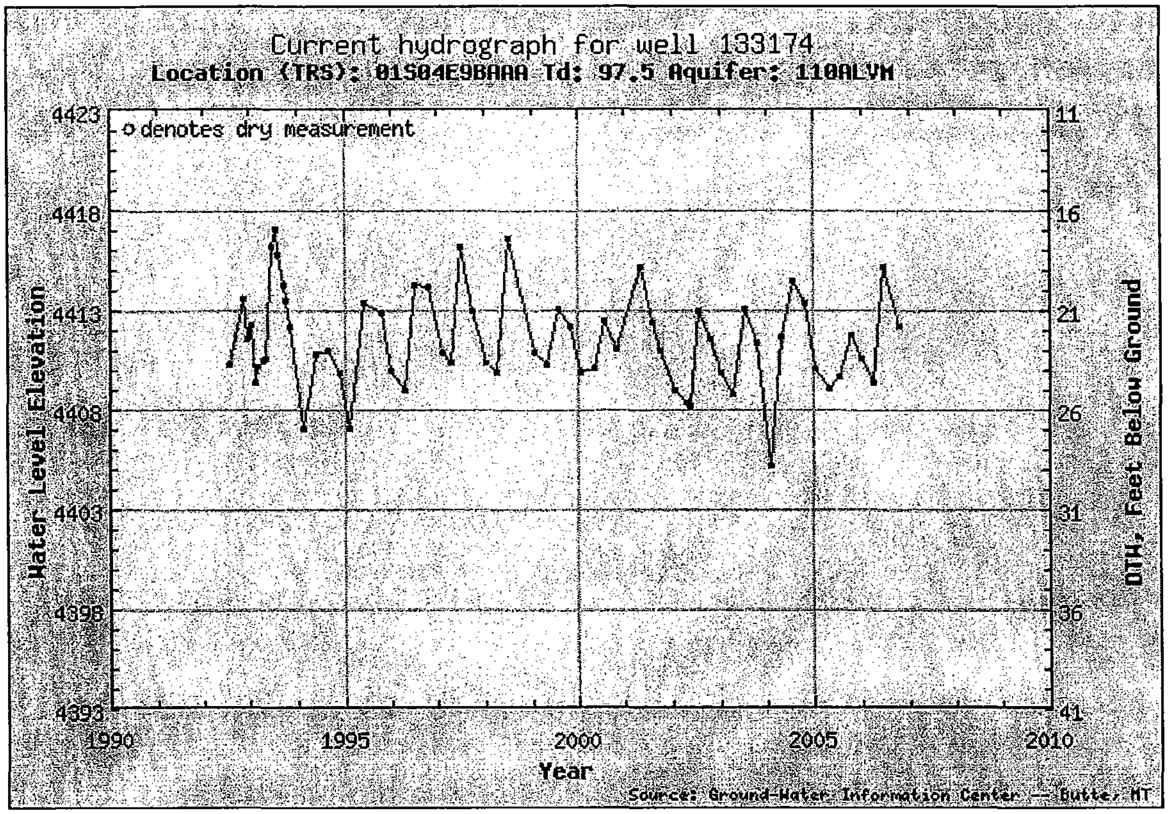
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 133172
Site Name: US GEOLOGICAL SURVEY - KAMMERMAN
Location: 01S03E36BCCD
Total Depth: 113 feet
Number of Measurements: 64
Period of Record: 9/29/1992 - 10/22/2006 10:00:00 AM

Ground-Water Infomation Center Well Hydrograph

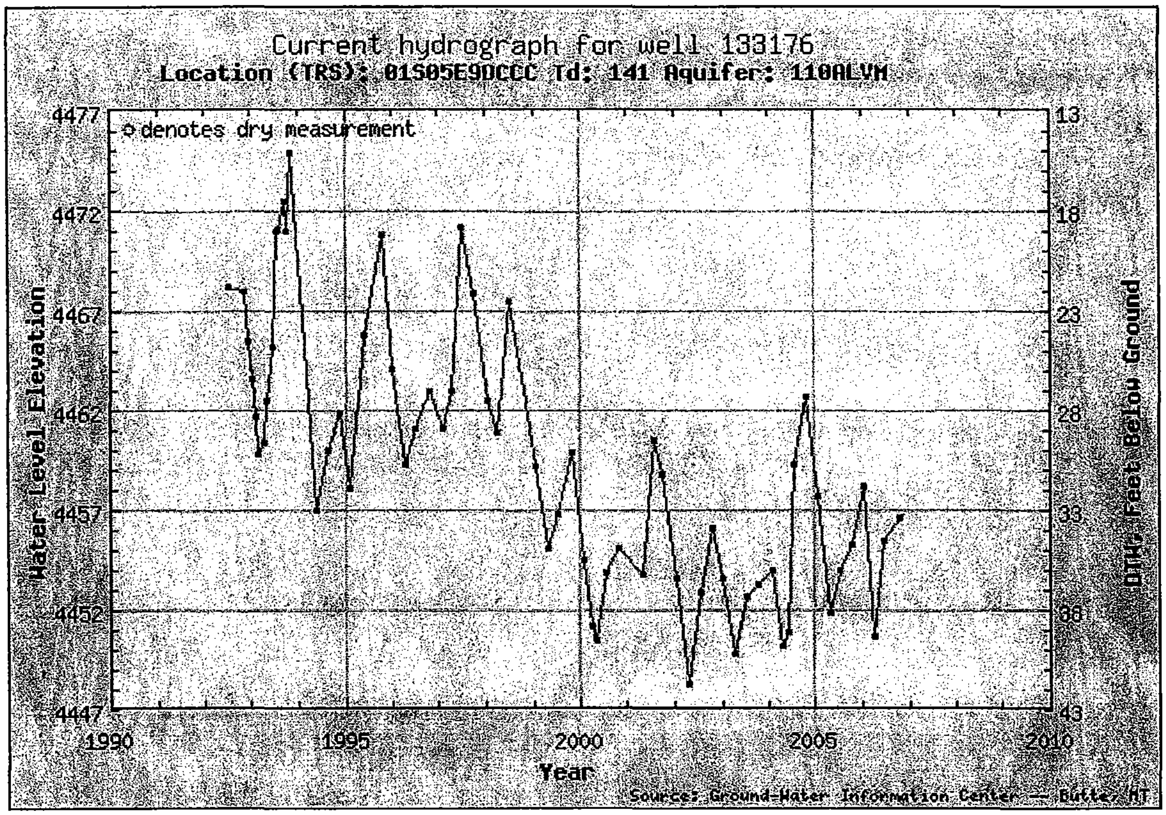
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 133174
Site Name: US GEOLOGICAL SURVEY - TORGERSON
Location: 01S04E9BAAA
Total Depth: 97.5 feet
Number of Measurements: 64
Period of Record: 7/15/1992 - 10/22/2006 10:25:00 AM

Ground-Water Infomation Center Well Hydrograph

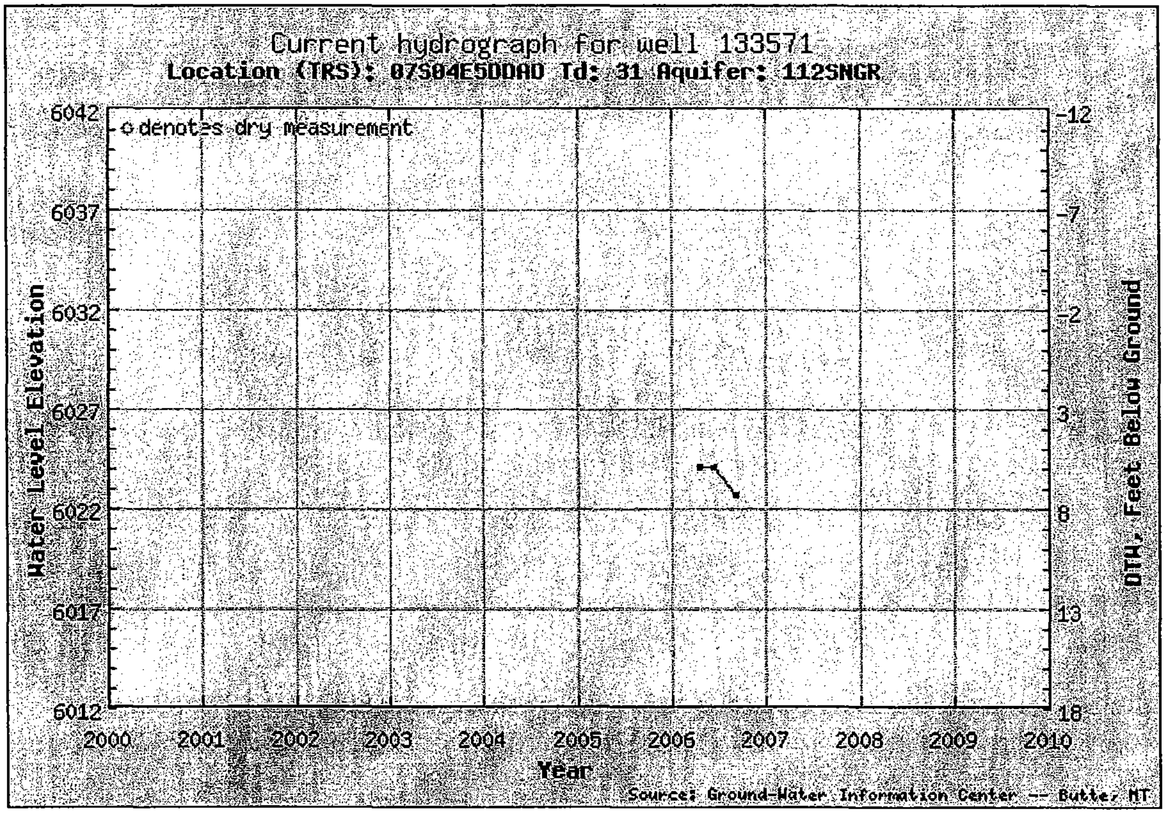
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 133176
Site Name: USGS OBSERVATION WELL NELSON RD
Location: 01S05E9DCCC
Total Depth: 141 feet
Number of Measurements: 64
Period of Record: 7/9/1992 - 10/21/2006 2:59:00 PM

Ground-Water Infomation Center Well Hydrograph

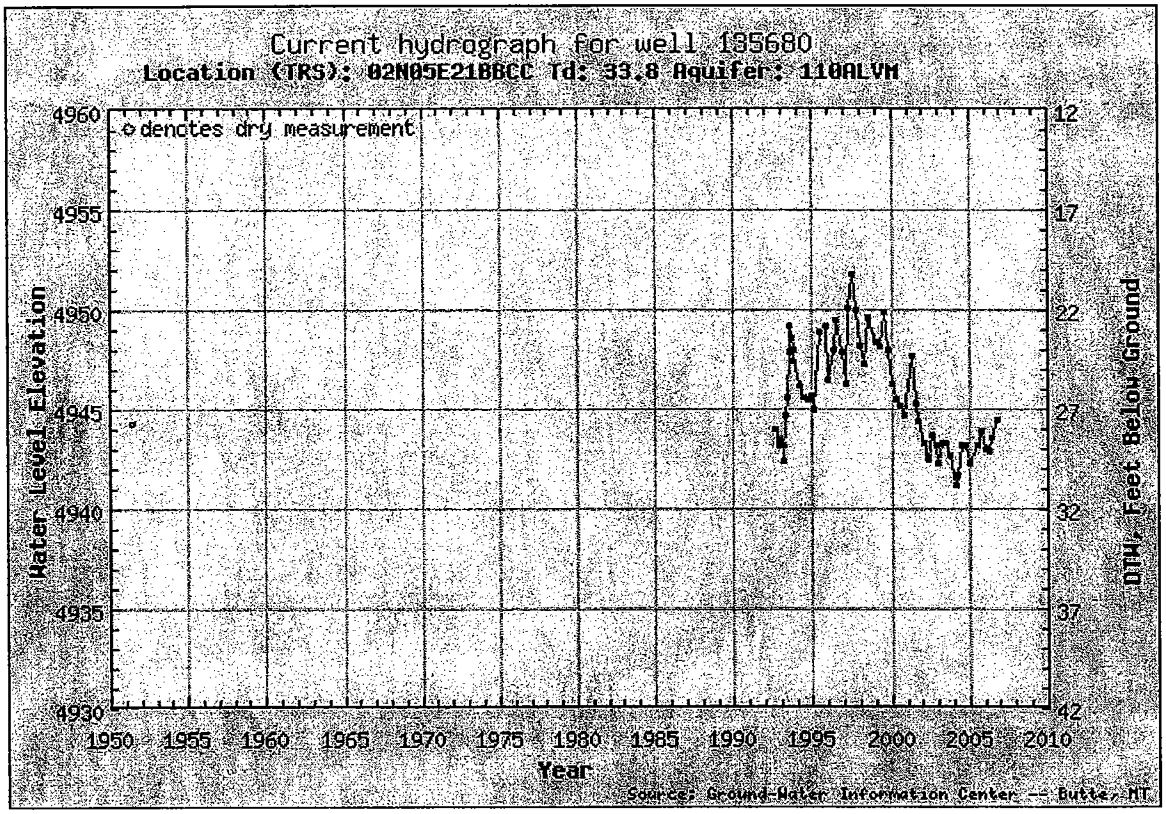
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 133571
Site Name: HAMMOND PROPERTY MANAGEMENT
Location: 07S04E5DDAD
Total Depth: 31 feet
Number of Measurements: 3
Period of Record: 4/20/2006 10:40:00 AM - 9/5/2006 9:37:00 AM

Ground-Water Infomation Center Well Hydrograph

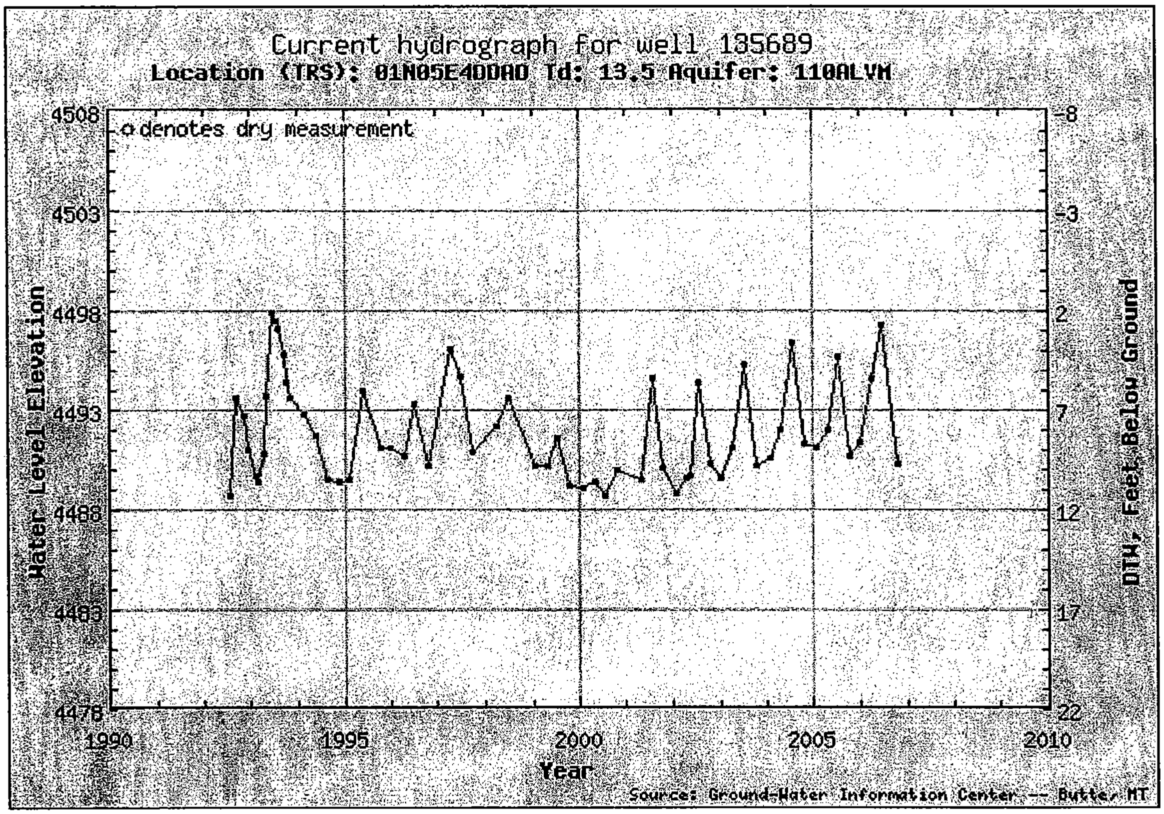
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 135680
Site Name: DRINGLE CHOP
Location: 02N05E21BBCC
Total Depth: 33.8 feet
Number of Measurements: 62
Period of Record: 5/28/1951 - 10/21/2006 5:01:00 PM

Ground-Water Infomation Center Well Hydrograph

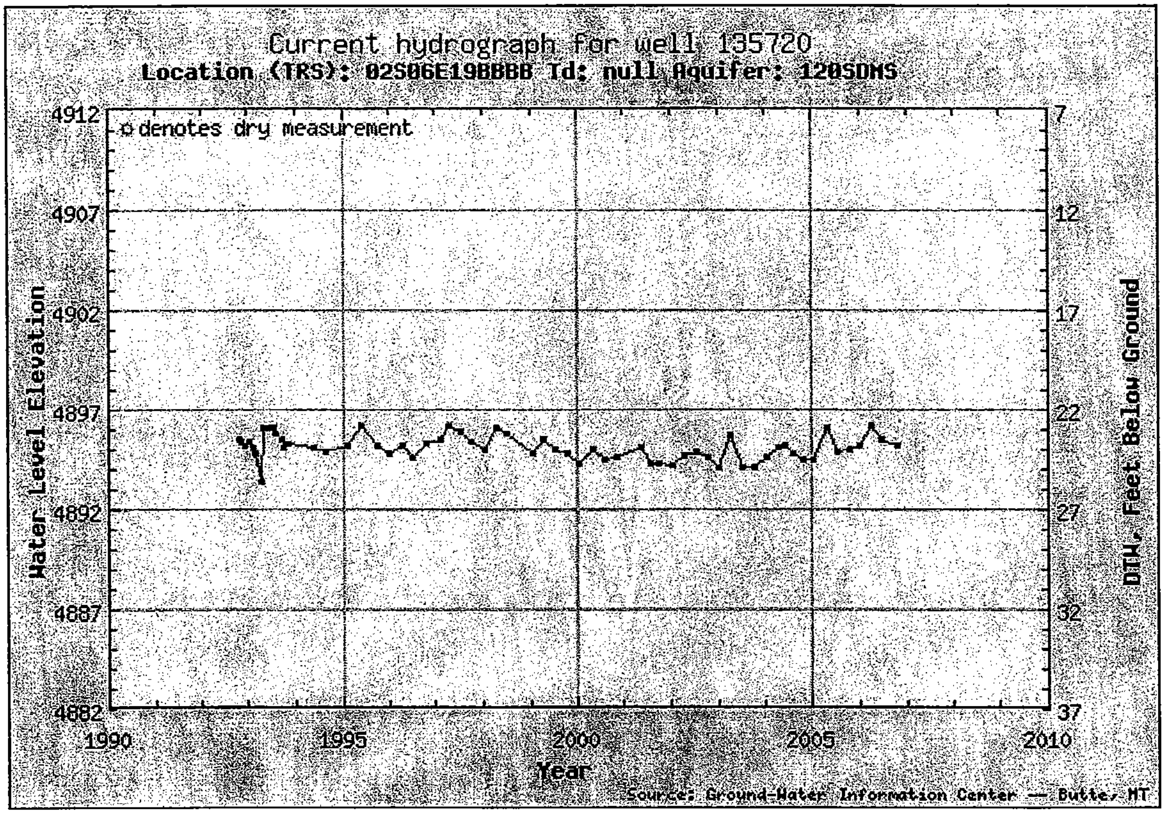
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 135689
Site Name: COOK RANCH
Location: 01N05E4DDAD
Total Depth: 13.5 feet
Number of Measurements: 62
Period of Record: 7/17/1992 - 10/21/2006 4:25:00 PM

Ground-Water Infomation Center Well Hydrograph

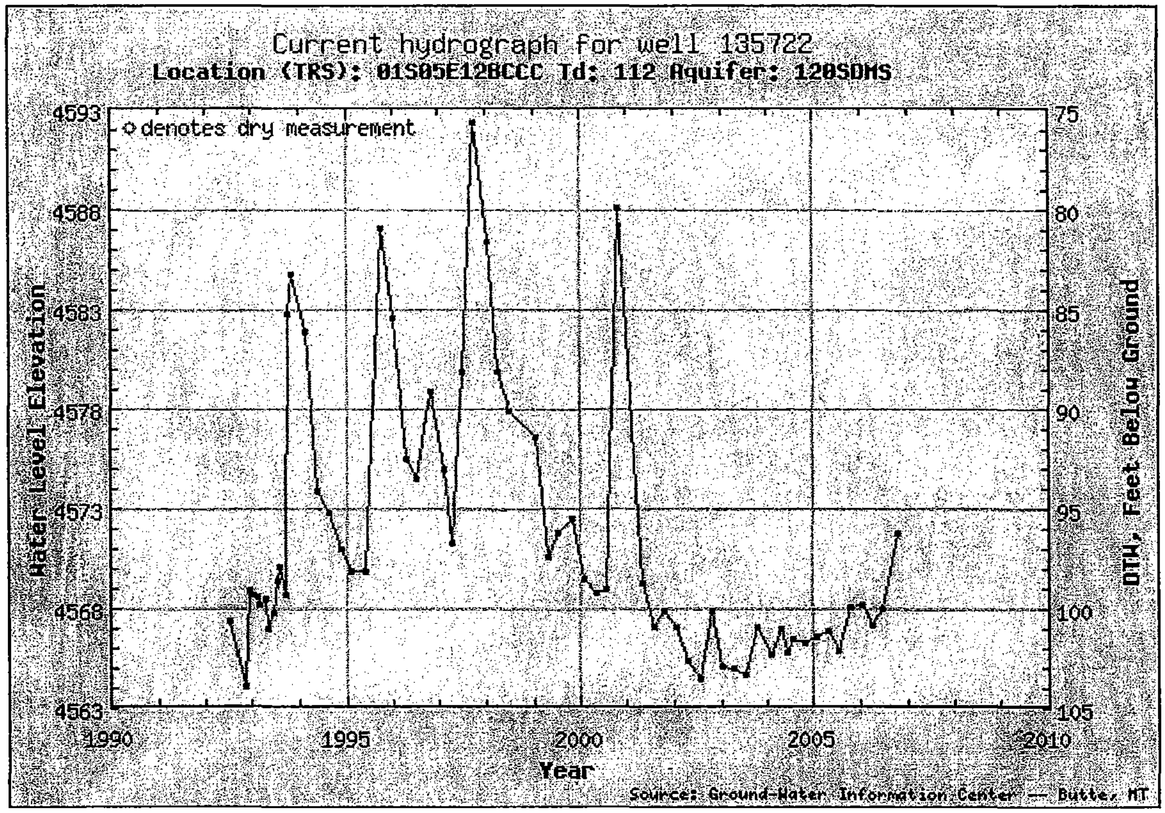
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 135720
Site Name: CITY OF BOZEMAN
Location: 02S06E19BBBB
Total Depth: feet
Number of Measurements: 62
Period of Record: 10/27/1992 - 10/22/2006 12:12:00 PM

Ground-Water Infomation Center Well Hydrograph

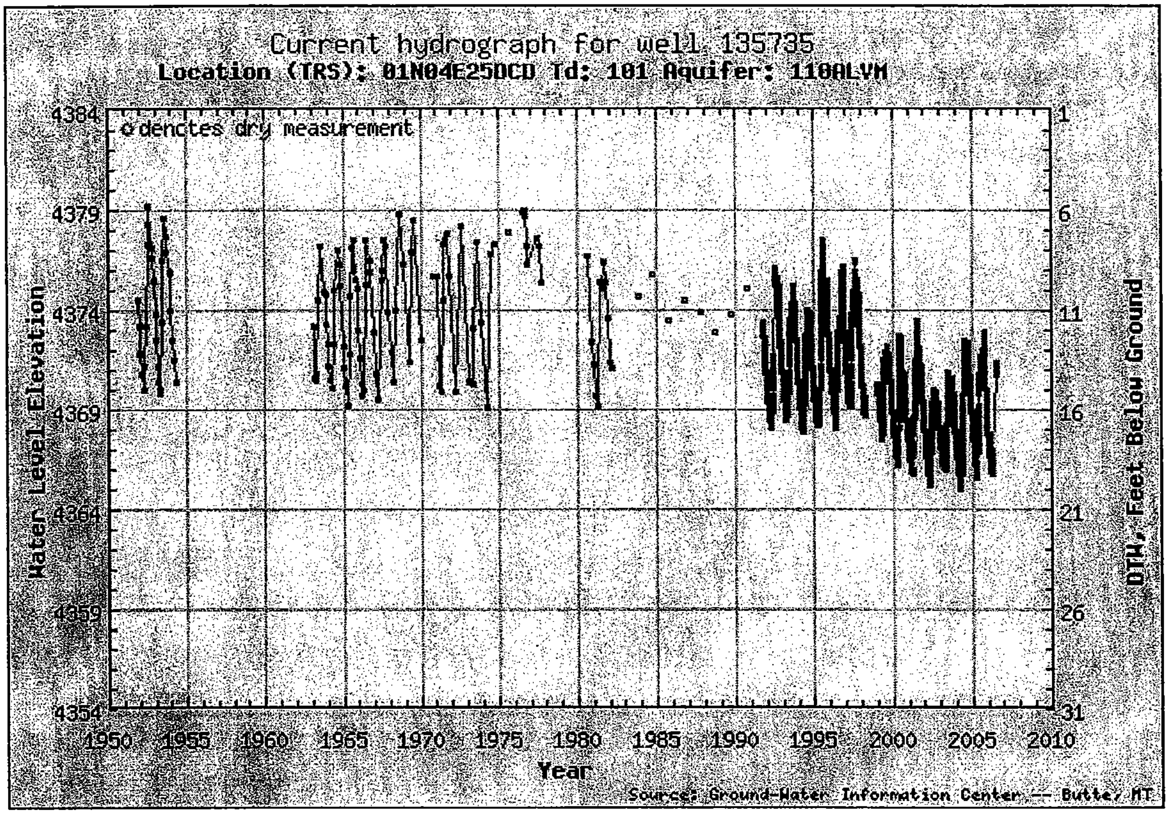
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 135722
Site Name: TOOHEY STEVE
Location: 01S05E12BCCC
Total Depth: 112 feet
Number of Measurements: 64
Period of Record: 7/9/1992 - 10/21/2006 3:21:00 PM

Ground-Water Infomation Center Well Hydrograph

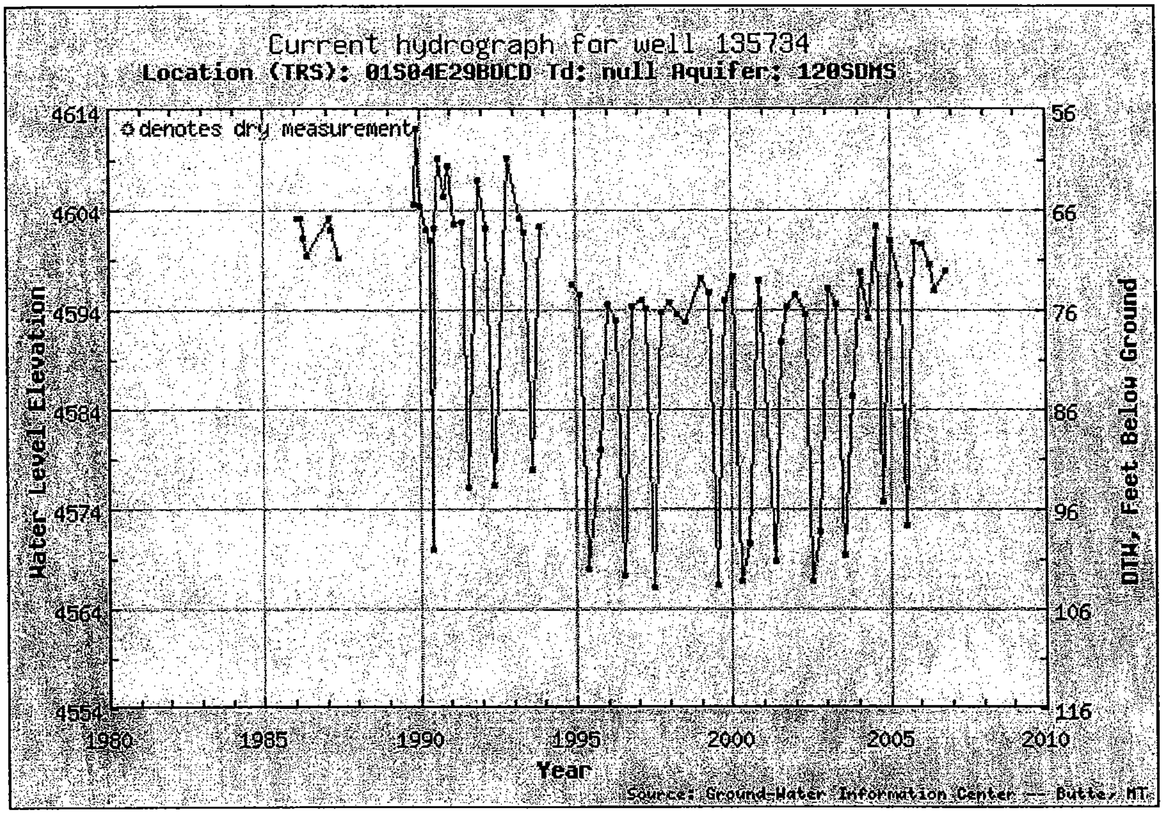
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 135735
Site Name: USGS OBSERVATION WELL
Location: 01N04E25DCD
Total Depth: 101 feet
Number of Measurements: 5174
Period of Record: 12/7/1951 - 7/26/2006

Ground-Water Infomation Center Well Hydrograph

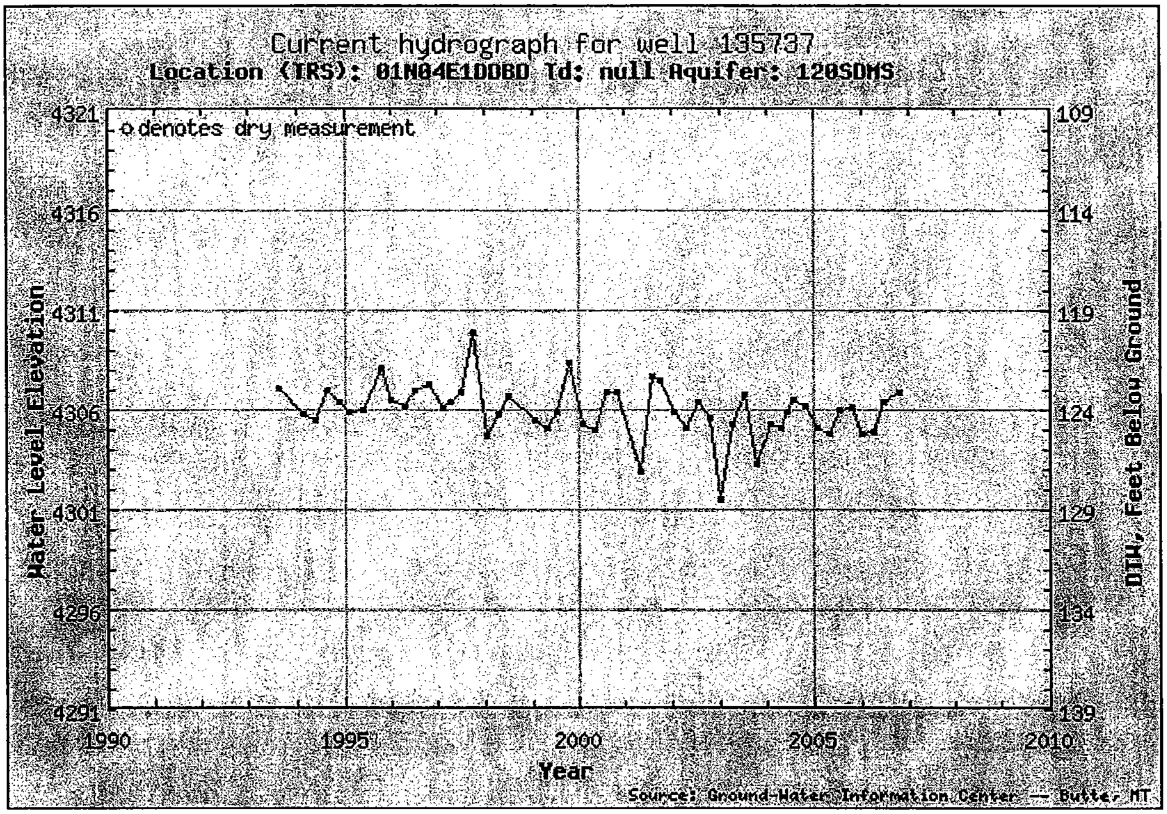
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 135734
Site Name: CLARENCE VAN DYKE
Location: 01S04E29BDCD
Total Depth: feet
Number of Measurements: 74
Period of Record: 1/30/1986 - 10/22/2006 10:12:00 AM

Ground-Water Infomation Center Well Hydrograph

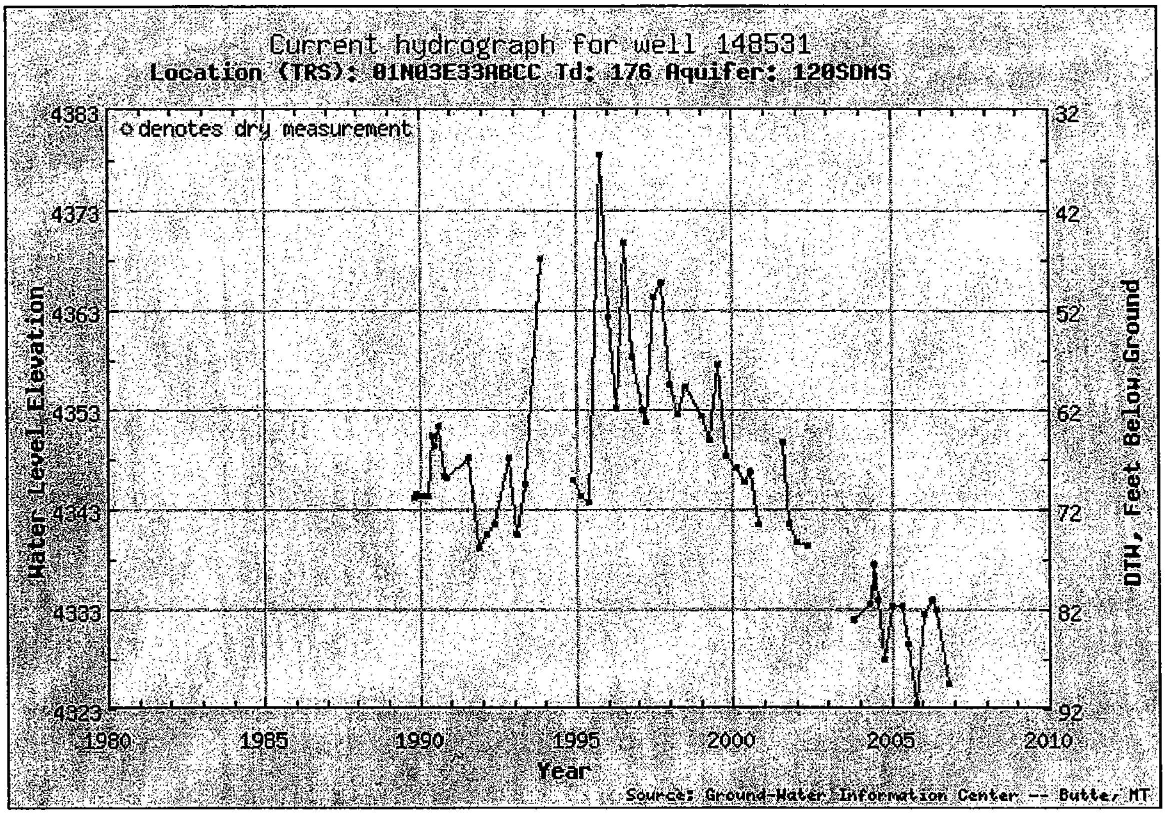
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 135737
Site Name: SCOGGINS JIM
Location: 01N04E1DDBD
Total Depth: feet
Number of Measurements: 52
Period of Record: 8/7/1993 5:46:00 PM - 10/21/2006 4:44:00 PM

Ground-Water Infomation Center Well Hydrograph

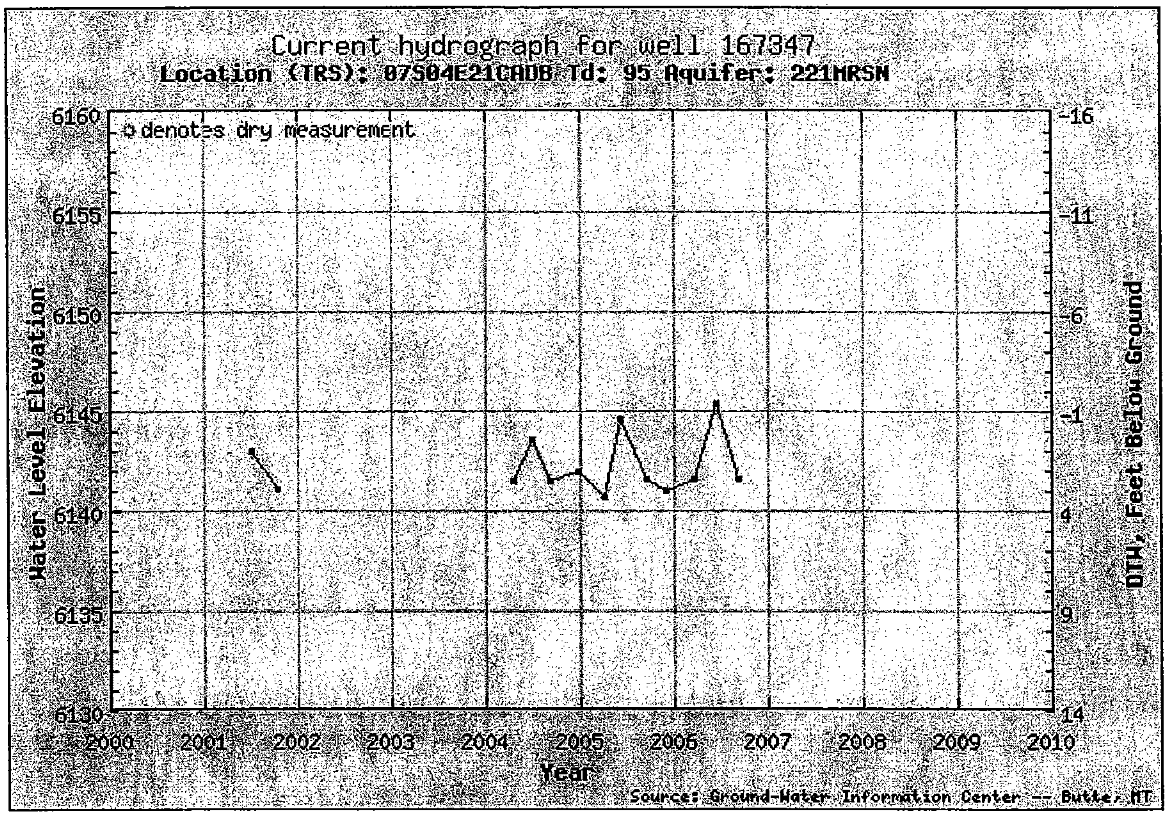
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 148531
Site Name: SCHUTTER JOHN
Location: 01N03E33ABCC
Total Depth: 176 feet
Number of Measurements: 59
Period of Record: 10/24/1989 - 10/21/2006 6:10:00 PM

Ground-Water Infomation Center Well Hydrograph

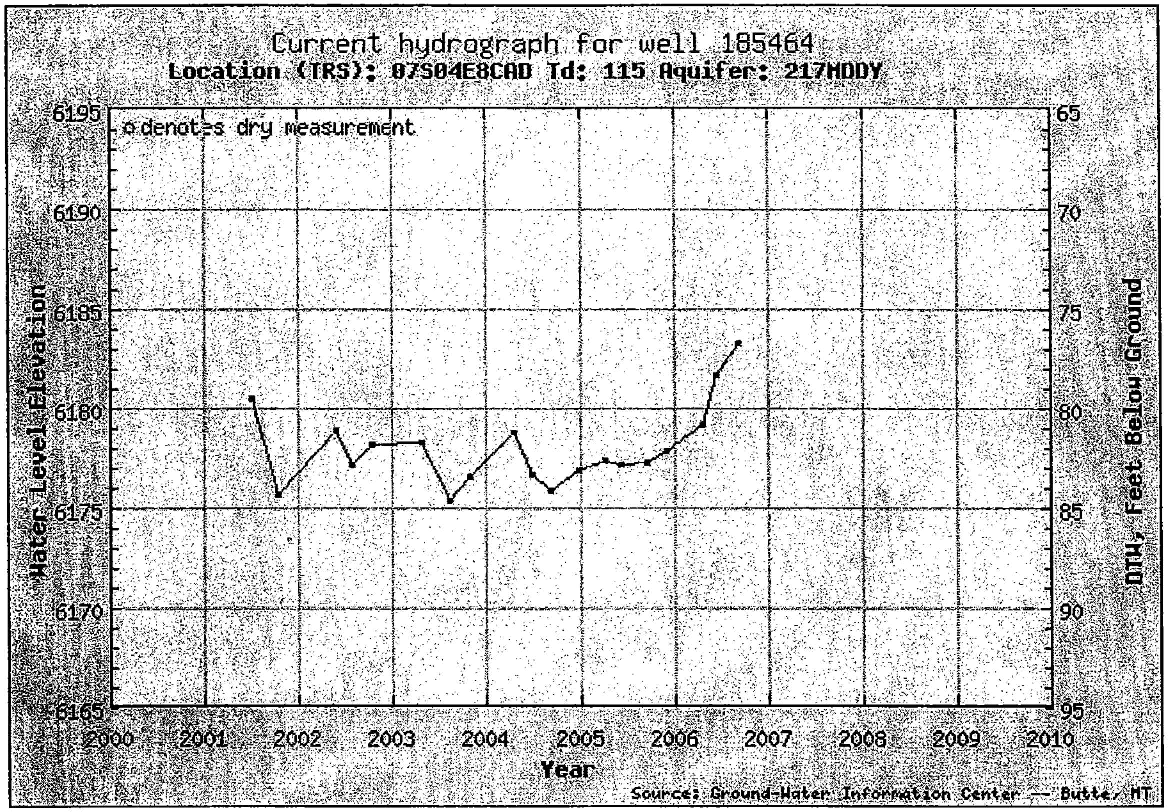
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 167347
Site Name: MONTANA DEPT OF TRANSPORTATION
Location: 07S04E21CADB
Total Depth: 95 feet
Number of Measurements: 13
Period of Record: 7/5/2001 2:38:00 PM - 9/5/2006 8:42:00 AM

Ground-Water Infomation Center Well Hydrograph

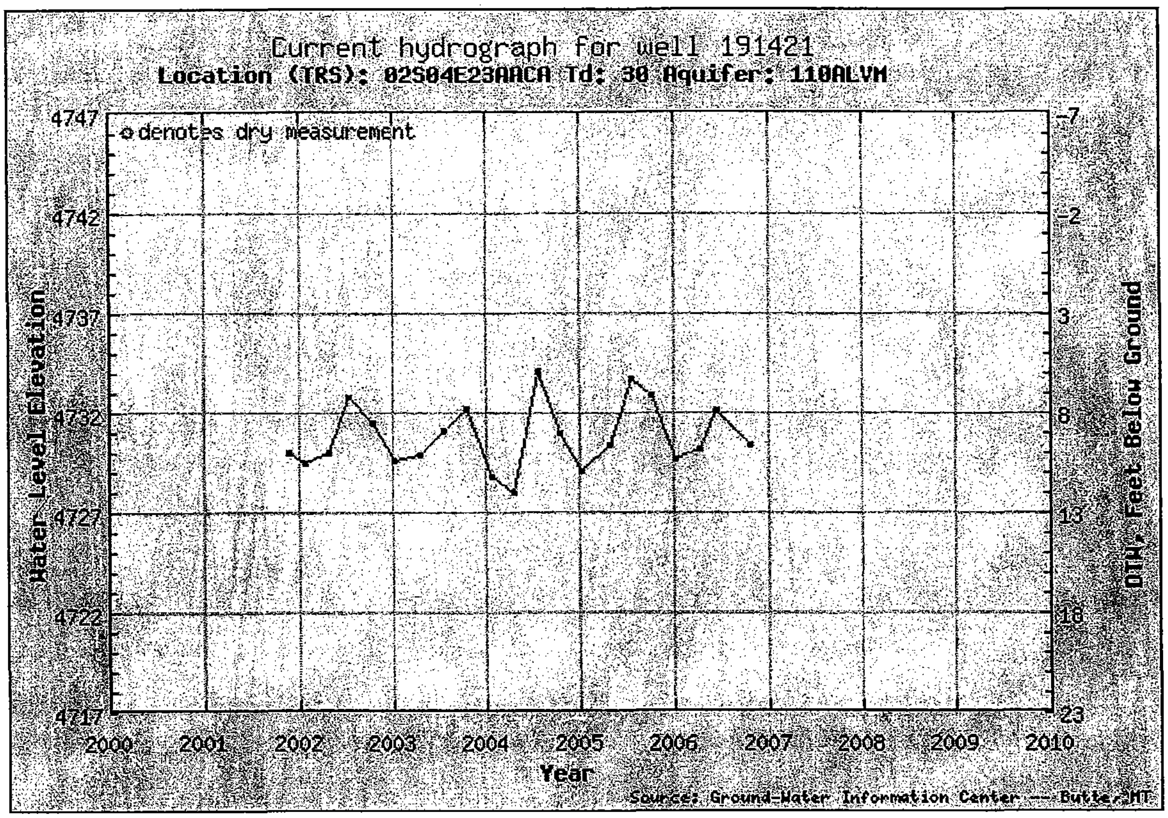
The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 185464
Site Name: HAMMOND SCOTT
Location: 07S04E8CAD
Total Depth: 115 feet
Number of Measurements: 19
Period of Record: 7/5/2001 9:51:00 AM - 9/5/2006 9:20:00 AM

Ground-Water Infomation Center Well Hydrograph

The following chart represents the current hydrograph for this well. Data reported are in feet below ground surface or feet above mean sea level.



GWIC Id: 191421
Site Name: JONGELING MIKE AND HEATHER
Location: 02S04E23AACA
Total Depth: 30 feet
Number of Measurements: 21
Period of Record: 11/20/2001 1:45:00 PM - 10/22/2006 9:45:00 AM