ABSTRACT

JORDAN, MICHAEL TERENCE. Effects of interbasin groundwater transfer on water and chemical budgets in lowland tropical watersheds- La Selva, Costa Rica. (Under the direction of David Genereux).

Small watershed budget studies are a major research tool in hydrology, ecology, and geochemistry. Most watershed hydrology and geochemistry studies attempt to avoid sites with groundwater seepage beneath topographic divides, known as interbasin groundwater transfer (IGT), due to the difficulty in quantifying it. However, IGT is an important and relatively common hydrological process that merits study. This project identified and quantified IGT by making detailed physical and chemical measurements in two adjacent lowland rainforest watersheds in Costa Rica: the Arboleda watershed, which receives IGT, and the Taconazo watershed, which is not affected by IGT. Physical hydrologic data allowed total IGT (mm/year) to be quantified in the context of water budgets for the watersheds, and the combination of physical and chemical data together allowed the IGT to be quantitatively separated into two components (high-solute bedrock groundwater and low-solute local water). Physical measurements of change in groundwater storage using piezometers, rainfall using a tipping bucket rain gauge, and stream discharge using V-notch weirs were made for four consecutive budget years. Major ion concentrations were measured in bulk rainfall samples, streamwater samples, and groundwater samples. The physical and chemical data were used to calculate annual water and chemical (Cl, SO_4, Na, K, Mg, Ca) budgets for the two study watersheds. The watersheds had equal annual rainfall and ET (averaging 4,973 mm/yr and 2,107 mm/yr, respectively), but the Arboleda also had additional large water inputs by IGT (averaging about 4,367 mm/yr from bedrock groundwater and 5,590 mm/yr

from local water). IGT to the Taconazo (all local water) was negligible (328 mm/yr). IGT of bedrock groundwater was mainly responsible for the Arboleda watershed receiving 18 times more Cl, 11 times more SO_4, 36 times more Na, 54 times more K, 220 times more Mg, and 71 times more Ca input than the Taconazo watershed. Total solute input to the Arboleda watershed is dominated by bedrock groundwater, which accounts for an average of 84 percent (SO_4) to 99 percent (Mg) of total solute input as compared with the Taconazo watershed where total solute input is controlled by rainfall accounting for on average of 77 percent (Mg) to 91 percent (SO_4) of total solute input. The Arboleda watershed was in a steady state condition (i.e., the difference between inputs and outputs was within the range of uncertainty) for each solute during the 12/00-11/01 and 12/02-11/02 budget years, as was the Taconazo for Na and Ca in both budget years and Cl in the second budget year. The Taconazo chemical budgets showed an excess of SO_4 inputs over outputs (+88 mol/ha and +115 mol/ha), a net loss of K (-165 mol/ha and -162 mol/ha), and a net loss of Mg (-256 mol/ha and -330 mol/ha). Traditionally, most watershed budget studies are conducted on the assumption that the watershed is "tight"; however, the results of this study clearly indicate that caution should be used in making such an assumption. Results also suggest a linkage between deep groundwater systems and lowland rainforest may be important to watershed science, water quantity and quality, water management, and conservation of lowland rainforest ecosystems.

EFFECTS OF INTERBASIN GROUNDWATER TRANSFER ON WATER AND CHEMICAL BUDGETS IN LOWLAND TROPICAL WATERSHEDS- LA SELVA, COSTA RICA

by
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BIOGRAPHY

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Chapter 1: INTRODUCTION

The hydrologic cycle continues to be a topic of primary scientific interest. Despite the relatively simple conceptual nature of the hydrologic cycle, it can often times be problematical to study due to the difficulty in precisely measuring some of its components. Groundwater seepage beneath topographic divides, known as interbasin groundwater transfer (IGT), is one component of the hydrologic cycle that is typically ignored due to difficultly in quantifying it (Bruijnzeel 1990). Most watershed hydrology and geochemistry studies attempt to avoid IGT by selecting sites that are believed to be "tight" (i.e., have no interbasin groundwater transfer) (Bruijnzeel 1990).

While IGT is typically not addressed, it is an important hydrologic process that has been found to occur throughout the world. IGT can be quantified (or at least detected) in a number of ways, including watershed budgets, chemical evidence, and head data. Head data were used to suggest the possibility of IGT in regional flow systems in Nevada (Winograd 1962) and Texas (Darling et al. 1997). Chemical data were used in investigations in the western U.S. (Thyne et al. 1999; Johannesson et al. 1995, 1997). Water and chemical budgets have been used to suggest the presence of IGT at small watersheds in Tennessee (Genereux et al. 1993; Luxmoore and Huff 1989), Malaysia (Yusop 1989; Rahim and Yusop 1986; Kenworthy 1971), Brazil (Brinkmann 1983, 1985), and Taiwan (Horng et al. 1985) (the Malaysia, Brazil, and Taiwan results are summarized by Bruijnzeel 1990, 1991).

Watershed budgets involve measuring inputs and outputs (and, if applicable, changes in storage) of water and/or chemicals on a watershed. IGT cannot be measured directly but can often be calculated as the unmeasured residual in a watershed budget calculation.

Numerous studies have sought to estimate the components in water and chemical budgets (e.g., Sun et al. 2002; Flerchinger and Cooley 2000; Cey et al. 1998). Primarily due to concerns related to deforestation, tropical forested watersheds have recently been the focus of several budget investigations (e.g., Soares and Almeida 2001; Cook et al. 1998; Cavelier et al. 1997; Lesack 1993a, 1993b; Bruijnzeel 1990, 1991).

In addition to being a subject of pure scientific interest in hydrology, a better understanding of IGT has several practical applications. A more thorough knowledge of water and chemical budget fluxes into and through watersheds can provide a better understanding of biogeochemical processes and solute transport (Likens and Bormann 1995; McDowell and Asbury 1994; Lesack 1993b). IGT may also have significant ecological implications for terrestrial (e.g. wetland) and aquatic ecosystems including effects on species diversity, rates of algal growth, and microbially-mediated decomposition of organic matter (Rosemond et al. 2001; Ramirez 2000; Pringle 1993). The identification of IGT is important because it may illustrate the presence of hydrogeological heterogeneities in discharge areas. Also, the detection of IGT increases the importance of regional (as opposed to local) land use planning for areas overlying the IGT system. If the clearing of land in IGT recharge areas reduces or contaminates the regional groundwater system supplying the IGT, the quantity and quality of water discharged in distant, lowland watersheds could be greatly affected (Genereux et al. 2002). Changes in land use patterns can have other major impacts that cannot be understood without further knowledge of the hydrologic cycle. More detailed data of the hydrologic cycle are needed to provide insight into questions pertaining to local and global climate change related to deforestation (Holscher 1997; Lesack 1993a; Shuttleworth

1988), change in available water supply for drinking and irrigation (Soares and Almeida 2001; Calder et al. 1986), and a change in soil fertility and abundance of nutrients (Klinge et al. 2001).

Watershed budget studies are well-suited to addressing many of these critical problems. However, many previous studies have ignored the possible role of IGT due to the difficulty in quantifying it (Bruijnzeel 1990). Rather than avoid IGT, the project is specifically designed to identify and quantify IGT by making detailed physical and chemical measurements in two adjacent lowland rainforest watersheds in Costa Rica: the Arboleda watershed, which receives IGT, and the Taconazo watershed, in which IGT has little or no influence. The work described here uses the paired-watershed approach; physical and chemical data were used to calculate water and major ion chemical budgets for the two study watersheds. The watersheds are nearly identical in terms of vegetation, soils, geology, topography, evapotranspiration, and amount and chemistry of rainfall. However, the streams draining the watersheds differ greatly in their chemistry and volumetric discharge rates, with the Arboleda having higher solute concentrations and significantly greater discharge. By computing and comparing water and chemical budgets for the watersheds described above, the work presented here makes a novel contribution to the understanding of IGT and lowland rainforest hydrology/geochemistry.

Chapter 2: PAST WORK

Because IGT cannot be directly measured, it is usually difficult to detect. Three possible ways to detect the presence of IGT are through the use of head data, chemical evidence, and water budgets. Head data is limited in that it can only indicate the direction of IGT. In order to quantify the actual IGT transfer rate, additional data on hydraulic conductivity and on the cross-sectional area of flow would be required. Head data were used to suggest the possibility of IGT in regional flow systems in Nevada (Winograd 1962) and Texas (Darling et al. 1997).

The presence of IGT can also be determined through the use of chemical data. IGT is often determined by the observation of a stream or spring that is chemically very different than other water in the same watershed. When used by itself, chemical data can only confirm a net gain of groundwater into the watershed of interest (it cannot show a net loss). Chemical data were previously used in groundwater investigations in the western U.S. (Thyne et al. 1999; Johannesson et al. 1995, 1997). Thyne et al. separated local recharge from IGT of deep groundwater in metamorphic and igneous rocks based on Cl, SO_4, deuterium, and total dissolved solids (TDS). Johannesson et al. (1995, 1997) employed a mass balance approach based on rare earth elements (REE) to determine the percentage of two chemically distinct waters required to produce the resultant discharge concentration observed in Furnace Creek springs.

Water and chemical budgets can be effective tools for identifying IGT. In the case of water budgets, evidence for IGT can be found from a stream discharge that is much greater than would be expected from the watershed rainfall inputs minus evapotranspiration (ET).

The water budget approach typically requires long-term, accurate measurements of stream discharge, rainfall, and ET. Though in some cases where interbasin transfer is very large (e.g., the Arboleda watershed) the presence of IGT is apparent with only approximate estimates of the water budget components. It should also be noted that the water budget method determines only a net gain or loss from the watershed. The actual rates of interbasin inseepage or outseepage, both of which could potentially occur in a regional gradient, cannot be separately determined.

Though it is possible to detect IGT with water budget studies, IGT is generally not included in the budget calculations due to the difficulty in quantifying it (Cook et al. 1998; Lesack 1993; Bruijnzeel 1990). Several budget studies have sought to quantify water and chemical movement by calculating budgets, but did not include IGT (e.g. Sun et al. 2002; Flerchinger and Cooley 2000). Lately, tropical forests have been the focus of several budget investigations due to their importance as natural resources (e.g. Soares and Almeida 2001; Cook et al. 1998; Cavelier et al., 1997; Lesack 1993a, 1993b; Bruijnzeel 1990, 1991). While IGT does not occur in all watersheds, failure to account for it in the budget calculations was the most common methodological shortcoming noted in a review of 25 budget studies in tropical areas (Bruijnzeel 1990, 1991).

Bruijnzeel identified several additional sources for error in these studies. Of the problems noted, several studies did not use flow control structures in the calculation of stream discharge. A flow control structure, such as a weir, is needed in rainforests where stream channel geometry may be frequently changed by organic materials. Other studies, which were less than one year in length, had difficulty accounting for seasonal variation in input and output fluxes. Additional experiments computed evapotranspiration (ET) as a residual rather than measuring it directly with a more accurate but also more expensive micro-meteorological approach (Lesack 1993a; Bruijnzeel 1990, 1991). Also, variation in stream solute concentration is expected due to the frequent storms typical of tropical forests (Lesack 1993b). Yet, some budget studies avoid the idea of change in solute concentration with discharge by not including it into estimates of export flux (Lesack 1993b).

By accounting for the previously mentioned methodological weaknesses of water and chemical budget studies, the results from the work described here were used to quantify IGT with a greater degree of certainty.

Chapter 3: STUDY SITE

3.1. Location and Area

The two watersheds of interest, the Taconazo and Arboleda, are located within La Selva Biological Station (Figs. 1, 2). La Selva is located in northeastern Costa Rica (Fig. 3) at the confluence of the Sarapiqui and Puerto Viejo rivers in the province of Heredia (10^{o} 26' N, 83^{o} 59' W) (McDade and Hartshorn 1994), and is owned and operated by the Organization for Tropical Studies, OTS (*www.ots.duke.edu*). The Taconazo and Arboleda watersheds contain the Taconazo and Arboleda streams, respectively. Both of these streams discharge to El Sura River.

The area of the Taconazo watershed was calculated to be approximately 26.36 hectares using ArcGIS with the spatial analyst, 3-D analyst, and hydrology extensions. The hydrology extension is available from ESRI (*http://www.esri.com*). Coverages of the streams and contour lines on 1-meter and 10-meter intervals were obtained for La Selva from OTS (w*ww.ots.duke.edu*).

Using 3-D analyst, TINs were created using the 1-meter and 10-meter contour coverages. The 10-meter TIN was converted to raster data. Using the hydrology extension, the flow direction and flow accumulation were calculated for the 10-meter contour data. The watershed was delineated based on the flow direction and accumulation. The raster watershed was converted back to vector format. Since basins smaller than the Arboleda were identified, the appropriate sub-basins were joined together. The computer-generated watershed for the Arboleda was manually fine tuned by comparing it against the 1-meter contours and 1-meter TIN. In areas that did not match, watershed vertices were moved, inserted, or deleted as needed.

The area of the Taconazo watershed was calculated based on the newly delineated watershed boundary. The area was determined using the visual basic script below:

```
Dim dblArea as double
Dim pArea as IArea
Set pArea=[shape]
dblArea=pArea.area
area_sq_m = dblArea
```

The area of the Arboleda watershed was found to be 50.02 hectares using the same procedure described above for the Taconazo.

3.2. Geology

La Selva is located on the Caribbean side of the Cordillera Central mountain chain. The Cordillera Central was formed by the subduction of the Cocos Plate beneath the Caribbean Plate, located to the east of the Cocos Plate. La Selva is approximately 35 km north of Volcan Barva at the edge of the active volcanic arc and the beginning of the back arc basin (McDade and Hartshorn 1994; Alvarado 1990). There is increasing volcanism along the mountain chain moving northwest towards Volcan Poas and Volcan Arenal.

The geology at La Selva is mainly associated with eruptions from Volcan Barva. Alvarado (1990) recognized three lower Pleistocene lava units at La Selva based on lithic fragments in soils, boulders, and limited outcrops. All three rock types, which are partially covered by upper Quaternary alluvial and swamp deposits in some areas, are present in the Arboleda or Taconazo watersheds (Fig. 4). The following discussion of the rock types found in the study watersheds was taken from the work of Alvarado (1990).

Alvarado (1990) recognized the Vargas basalt as the oldest of the three units. The Vargas basalt is slightly alkaline in composition and poor in magnesium. Weathered surfaces appear dark coffee brown to dark brown-orange and fresh surfaces appear light grey. Plagioclase accounts for 10-16.5% of the rock and is the dominant phenocryst (with some crystals reaching up to 2 cm in length). Phenocrysts of olivine (1-1.5%) are also present, though some crystals show alteration to iddingsite and serpentine. Pyroxene is notably absent from the phenocryst mineral assemblage. The matrix constitutes 79.5-86.0 percent of the rock and is made up of brown glass with abundant plagioclase, clinopyroxene, opaque minerals, and traces of olivine. Vesicles account for 0.5-1.5 percent of the rock. Chlorite, serpentine, and iron oxides were observed in the fractures of some samples. While the exact thickness of the lava was not determined, it is at least 2 meters thick. The Vargas basalt is found only along the central and lower sections of the Taconazo stream. It constitutes 16.4 percent of the area of the Taconazo watershed.

The other two lava units identified by Alvarado (1990) are the Salto basaltic andesite and the Esquina andesite, and concluded that they formed from the partial melting of mantle peridotite followed by fractional crystallization of olivine and pyroxene.

The Salto basaltic andesite is intermediate in age between the Taconazo andesite and the Esquina andesite. The Salto unit is defined by pyroxene andesites with olivine. Fresh surfaces appear light grey to black. Plagioclase constitutes 10 to 25 percent of the rock (some phenocrysts are up to 3 cm in size). Some plagioclase crystals display weathering to clay. Olivine crystals, some of which were altered to iddingsite, serpentine, and occasionally calcite, make up 2.5 to 4.5 percent of the rock. Clinopyroxene phenocrysts (2.5-4.5%) may have inclusions of magnetite, plagioclase, or olivine. Orthopyroxene is present, but not abundant. The matrix comprises 65 to 80 percent of the rock and is composed of brown glass, plagioclase, opaque minerals, and sparse olivine. Vesicles may be present in 0.2 to 3 percent of the rock. The thickness of the unit increases toward the south up to at least 55 meters thick. El Salto andesite is found along the upper sections of the Arboleda and Taconazo streams. It comprises 5.7 percent of the Arboleda watershed and 7.0 percent of the Taconazo.

The Esquina andesite is the youngest of the three rock units identified by Alvarado. Radiometric dating estimates for the unit place it in the lower Pleistocene with an age of 1.2 million years. The rock is typically dark grey to black. When weathered, surfaces appear light grey to coffee brown. The rock has a porphyritic texture with phenocrysts of plagioclase (1-3.5%), clinopyroxene (0.2-3.0%), and orthopyroxene (0-1.5 percent). Vesicles constitute approximately 0.5 to 4.0 percent of the rock. The thickness of the Esquina andesite is approximately 20 meters on average, though it may be greater than 35 meters thick in some areas. The Esquina andesite is the most wide spread of the three rock types constituting approximately 72.4 percent of the area in the Arboleda and approximately 76.6 percent of the area in the Taconazo.

Organic-rich swamp deposits along the lower sections of the Arboleda stream cover a portion of the Esquina andesite. The swamp deposits rarely exceed a thickness of 1 meter and are typically between 10 to 40 cm thick (Sollins et al. 1994). The swamp deposits cover an area of 12.0 percent of the Arboleda watershed.

3.3. Soils

The formation of the soils in the Arboleda and Taconazo watersheds (Fig. 5) is primarily related to the "in-place" weathering of the volcanic rocks described above as well as the deposition of the fluvial sediments near streams and the accumulation of organic material in poorly drained regions (Sancho and Mata 1987). The soils in the watersheds are typical of volcanic soils in terms of their bulk density, water holding capacity, and clay content (Sollins et al. 1994).

Three different soil units were identified in the Arboleda watershed (Sancho and Mata 1987). The Arboleda soil series is the most widespread of the three and constitutes 61.8 percent of the watershed. While the Arboleda series may originate from the Esquina andesite, it is more likely that it is an alluvial soil originating from a very old river terrace (Sollins et al. 1994). The Arboleda series is generally acidic and base-poor and is classified as a Humic Dystrudept (Sollins et al. 1994).

The Jaguar series, which accounts for 26.2 percent of the total area, is present along the southern and western boundaries of the Arboleda watershed. It developed from the Esquina lava flow and is classified as a Typic Haplohumult. The Jaguar soils are characterized as strongly acid and rich in organic matter (Sollins et al. 1994).

Together, the Arboleda and Jaguar units comprise approximately 86.7 percent of the total area of the Arboleda and Taconazo watersheds. The two soil units are hydrologically similar in that they are clay-rich soils with good structure that allow water to drain freely through macropores (USDA 1999; Sollins et al. 1994). Water draining through macropores will bypass the soil matrix allowing solutes to flow through while the nutrients already present in the soil matrix will not tend to leach. The Arboleda and Jaguar soils were mapped as separate units based on different parent materials with the Arboleda being formed from a very old alluvial terrace compared with the Jaguar soils which are believed to be residual soils derived from the weathering of bedrock (Sollins et al. 1994). The Arboleda unit differs from the Jaguar unit in that the Arobleda soils tend to be less clay rich in the B-horizon (23 percent compared to 60 percent) and are slightly less acidic in the A-horizon (pH of 5.3 compared to 4.5) (Sollins et al. 1994).

The Pantano complex was mapped by Sancho and Mata (1987) in the swampy areas along the northern half of the Arboleda stream (note: if dissimilar soil units occur together and the contact between the two is too intricate to separate, it is mapped as a complex rather than a soil unit which receives a taxonomic name) (Sollins et al. 1994). The complex constitutes approximately 12.0% of the total area in the Arboleda watershed. The complex is defined by the occurrence of high water tables that allow for the accumulation of organic matter and cause reducing conditions.

The Taconazo watershed also contains the Jaguar and Arboleda soil series, which make up 84.0 percent and 0.4 percent of the total area of the Taconazo watershed, respectively. In addition, Sancho and Mata (1987) identified the Taconazo and Chanchera soil series in the Taconazo watershed.

The Taconazo soil series is found along the central and southern portions of the Taconazo stream, which roughly correspond to the locations of its parent material, the Taconazo andesite. The soil constitutes approximately 14.4 percent of the Taconazo watershed. The soil is characterized as being strongly acid (pH of 4.4 in A-horizon and 5.1

in B horizon) (Sollins et al. 1994). It has a slightly lower clay content than the other soil units (11 percent of the A-horizon and 36 percent of the B horizon) (Sollins et al. 1994). The presence of grey colors beginning at a depth of 22 cm below the surface indicates poor water drainage. Rock fragments are common in the upper portions of the soil. The soil is classified as a Typic Endoaquept due to its water table, which is within 50 cm of the ground surface in some locations.

The Chanchera series is located in the northwest corner of the Taconazo watershed and comprises the smallest area, 1.2 percent of the watershed. The soil series is identified as an Andic Dystrudept and is associated with the Rio Sarapiqui terraces. It is similar in acidity (pH of 4.3 in the A-horizon and 4.9 in the B-horizon) and clay content (22 percent in the A-horizon and 45 percent in the B-horizon) to the other soil units (Sollins et al. 1994).

3.4. Geomorphology

La Selva is located at the transition between the foothills of the Cordillera Central mountain chain and the Caribbean coastal plain (McDade and Hartshorn 1994). The geomorphology of land in the vicinity of Volcan Barva was formed by ash falls, lahars, and lava flows (Sollins et al. 1994). It is believed that ash falls could not affect the geomorphology of La Selva based on the direction of the prevailing winds (Sollins et al. 1994). Lahars have only had a minor influence on the terrain and did not affect the Arboleda or Taconazo watersheds (Alvarado 1990). The landscape at La Selva, including the Arboleda and Taconazo watersheds, was dictated by the three lava flows previously described.

In addition to the lava flows, alluvial deposits associated with the Puerto Viejo and Sarapiqui rivers have shaped the landscape. The deposits are divided into five terraces (Alvarado 1990). The soils in the northern portion of the Arboleda watershed were probably formed from the upper terrace associated with the Puerto Viejo River (Sollins et al. 1994).

3.5. Topography

The watersheds are located in the lowlands with elevations ranging from 35 to 86 meters in Taconazo watershed and 33 to 90 meters in the Arboleda watershed (Fig. 6). The topography in the watersheds consists of steep, undulating hills that are dissected by the streams. Slopes in the Taconazo watershed were found to average 14.0^{o} with a range of 0.0^{o} to 62.3^{o} based on a 1-meter contour analysis completed in ARCGIS. In the Arboleda watershed, ground surface slopes range between 0.0^{o} and 64.0^{o} with an average slope of 16.2^{o}.

3.6. Climate

La Selva is classified as a tropical wet forest. From 1958-2002, annual precipitation at La Selva averaged 4242 mm; monthly average precipitation during the same period ranged from 155 mm (February) to 527 mm (July) (OTS 2003; Sanford et al. 1994). The monthly rainfall is bimodally distributed with heavier rains occurring from May to June and from November to December; the dry season is from February to April.

La Selva is typical of the tropics in regard to the air temperature, which has been measured since 1984 and averages 25.8 ^{o}C monthly with less than 3 ^{o}C variation in average monthly temperature (Sanford et al. 1994). August is typically the warmest month (mean temperature

= 27.1 ^{o}C) and January the coolest (mean temperature = 24.7 ^{o}C) (McDade and Hartshorn 1994).

3.7. Vegetation

Land cover in the Arboleda and Taconazo watersheds is essentially 100 percent tropical rainforest, with over 75 percent representing primary, undisturbed rainforest and the remaining land split between forested swamps, 9.2 percent, and secondary rainforests, 15.1 percent. Primary forests in La Selva are dominated by *Pentaclethra macroloba*, which forms the base of the canopy at a height of 30 to 35 meters (Hartshorn and Hammel 1994). Many other tree species are scattered through this section of the forest at heights of 40 to 55 meters causing the forest canopy to be irregular.

The swampy area located along part of the Arboleda stream is characterized by different vegetation than the remainder of the watershed. *Pentaclethra* is still the major canopy species, but several other trees including *Carapa nicaraguensis*, *Luehea seemannii* Triana and Planchon (Tiliaceae), and *Otoba novogranatensis* Moldenke (myristicaceae) are present (Hartshorn and Hammel 1994).

3.8. Previous Stream Research at La Selva

Several streams located within La Selva have been the subject of previous study. A study of nutrient chemistry initially exposed the presence of solute-rich streams at low elevations in La Selva (Pringle et al. 1986). Pringle et al. (1990) later examined spatial chemical variability in the Sura watershed, which contains the Arboleda and Taconazo drainages, and the Salto watershed. The chemical variability was not found to be a function of the local geology or vegetation; rather, it was thought to occur due to deep groundwater high in dissolved solids discharging in lowland areas (Pringle et al. 1990). Further evidence for solute-rich groundwater discharge at La Selva was presented in the form of geochemical data by Pringle et al. (1993) and Genereux and Pringle (1997).

Genereux et al. (2002) made preliminary attempts to quantify the input of groundwater into the Arboleda and Taconazo watersheds through water budget calculations and also presented a two-component mixing model to quantify the mixing of high solute groundwater with low solute water in riparian areas as well as in stream channels.

The low solute water end-member is referred to as "local water." Local water is conceptually defined as low-solute drainage of near-surface soils at the study site. The high solute groundwater is known as "bedrock groundwater." Bedrock groundwater is characterized by high solute concentrations typical of regional groundwater that had a long residence time in contact with the bedrock. Unlike local water, which may or may not be IGT, bedrock groundwater present in the study is necessarily IGT. Conceptually, bedrock groundwater is viewed as the discharge of a deep, regional flow system. Most of the variability in major ion concentrations of natural waters at La Selva can be explained by mixing between these two end-members (Genereux et al. 2002; Genereux and Pringle 1997).

Major ion concentrations of the two end-member waters, local water and bedrock groundwater, were relatively constant over time. For sampling between 1993 and 1998, the chloride concentration was found to be 0.072 mM for the local water end-member and 0.903 mM for the bedrock groundwater end-member (Genereux et al. 2002). Major ion data from the present study (see Chapters 4 and 5) are consistent with the earlier data and the two-component mixing model.

It was possible to separate the high-solute bedrock groundwater from the low-solute local water in the stream samples through the use of chloride data (Genereux et al. 2002). By knowing the end-member concentrations for chloride as well as the chloride concentration of a given stream sample, it was possible to calculate the fraction of the stream sample that is due to bedrock groundwater discharge, f_{GS}. f_{GS} values at La Selva ranged from zero to a high of about 0.84 (Genereux et al. 2002). The f_{GS} values for sampling sites at higher elevations were zero or near zero indicating the discharge of bedrock groundwater seems to occur only at elevations less than 45 meters (Genereux et al. 2002). Dry season f_{GS} values for the Taconazo and Arboleda streams were 0.013 and 0.49, respectively, which supports the idea of the Taconazo having virtually all local water (the value of 0.013 is not statistically different from zero) whereas there is mixing of local water and bedrock groundwater in the Arboleda watershed (Genereux et al. 2002).

^{18}O data collected by Genereux (2003) also support the conceptual hydrologic model for mixing of high-solute bedrock groundwater (representing IGT) with low-solute local water, but could not be used to separate the two waters due to the high variability in the ^{18}O of the local water end-member.

Other investigations (Ramirez et al. 2003; Rosemond et al. 2002; Rosemond et al. 2001; Ramirez 2000; Pringle and Triska 1991) examined the effect of groundwater and solute transfer into lowland rainforest watersheds on stream hydrology, geochemistry, and ecology.

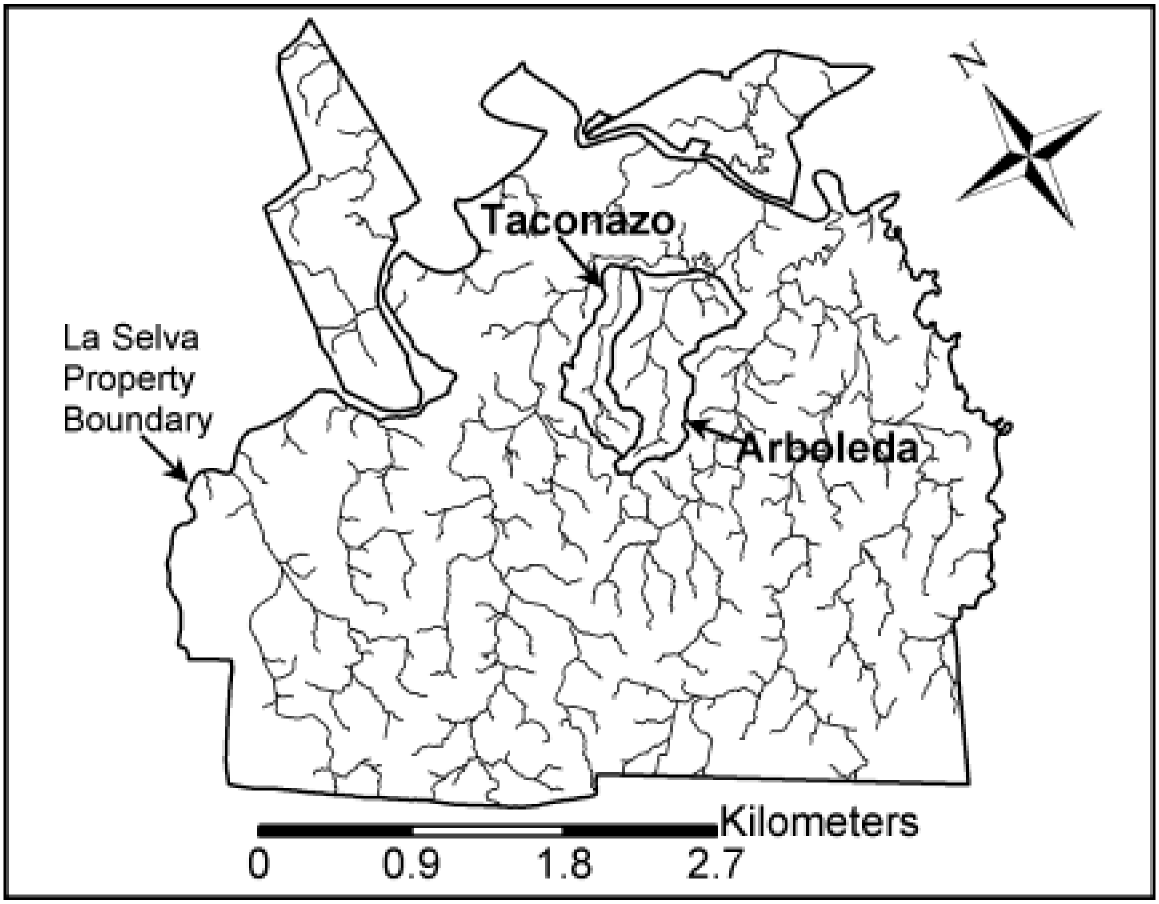


Figure 1. Map of La Selva Biological Station showing property boundaries, stream channels, and the two study watersheds (Taconazo and Arboleda).

GIS coverages created by La Selva GIS Laboratory, OTS.

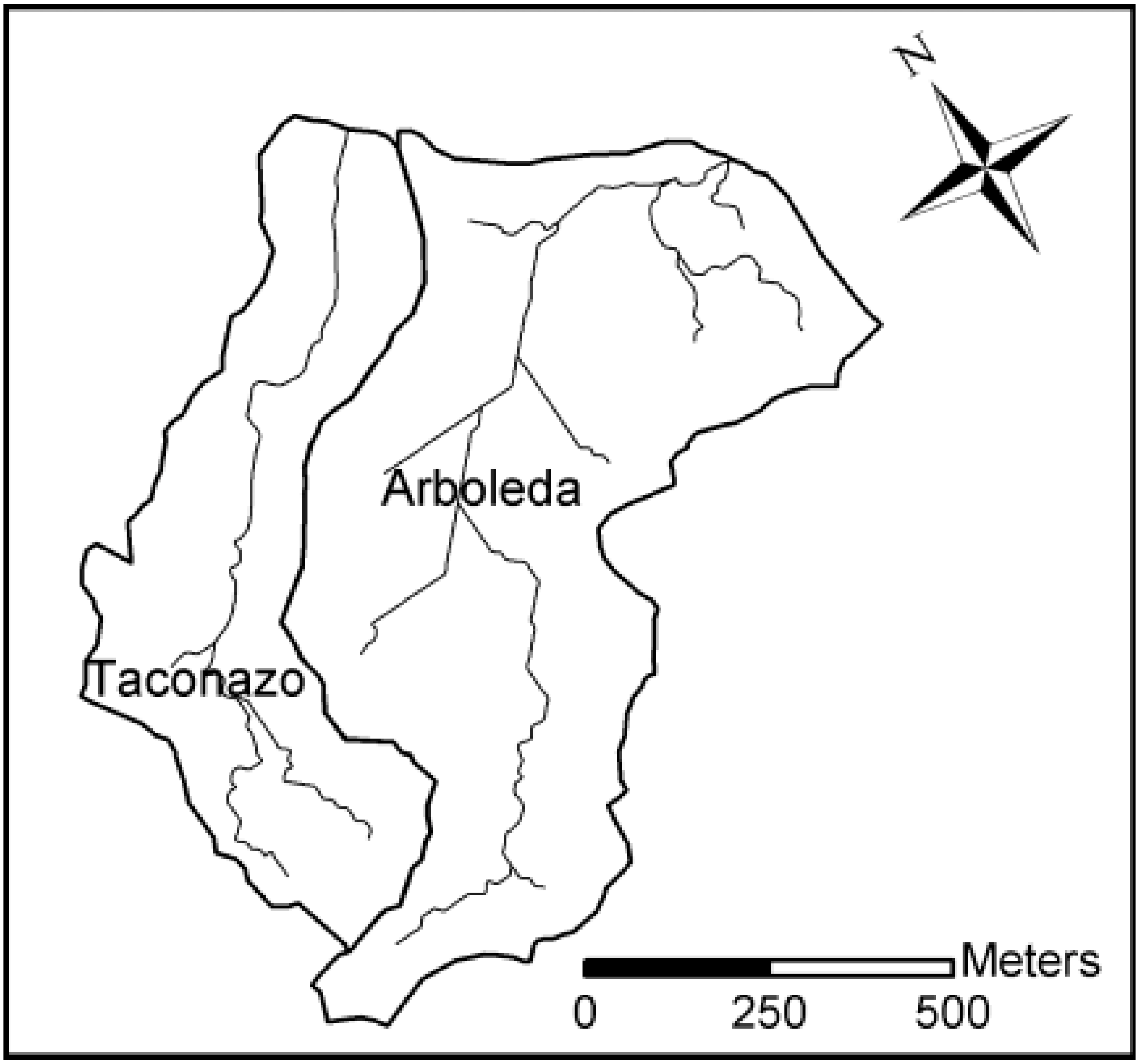


Figure 2. Boundaries and stream channels of the Arboleda and Taconazo watersheds.

GIS coverage of stream channels created by La Selva GIS Laboratory, OTS.

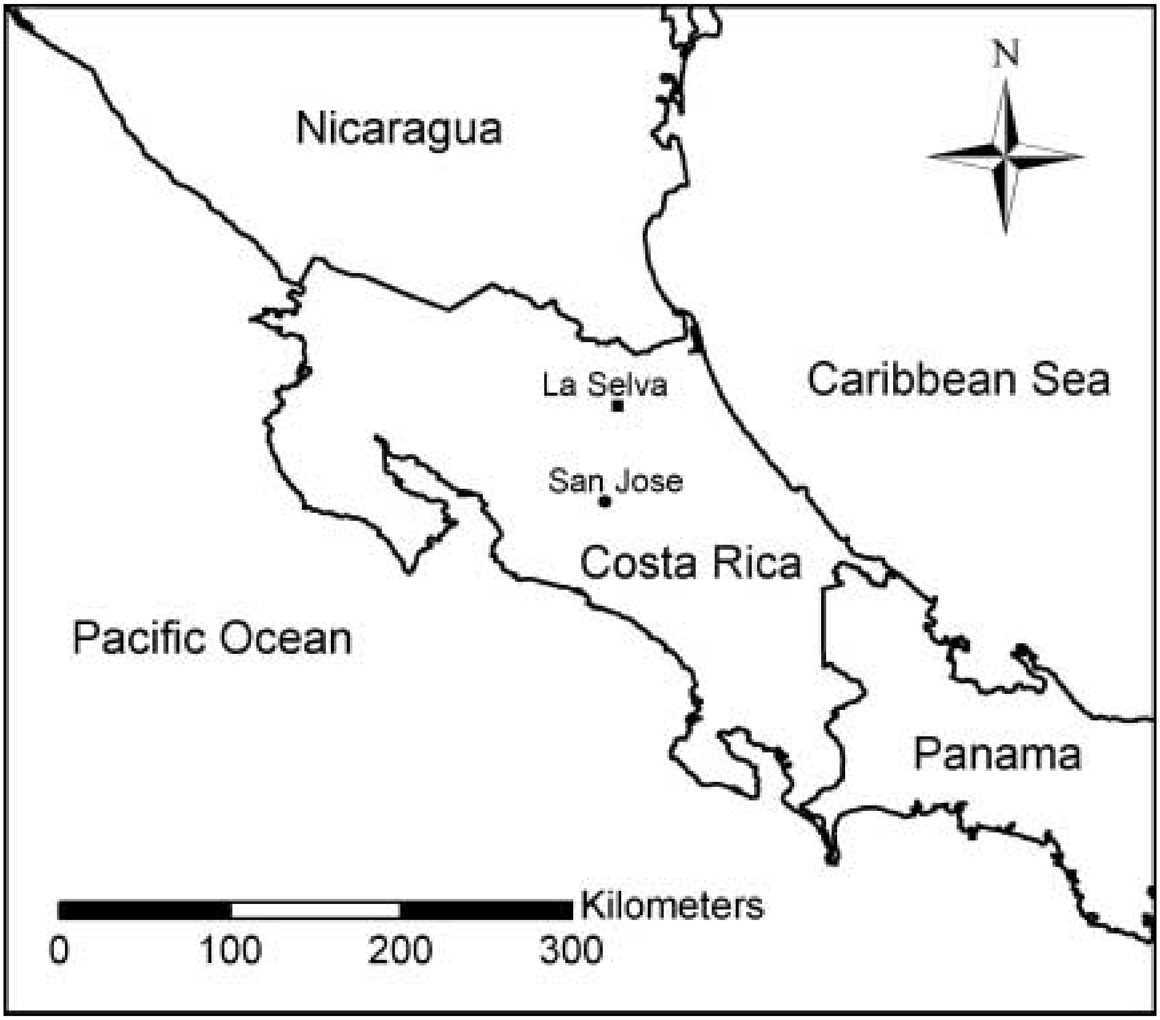


Figure 3.   Location of La Selva Biological Station within Costa Rica.

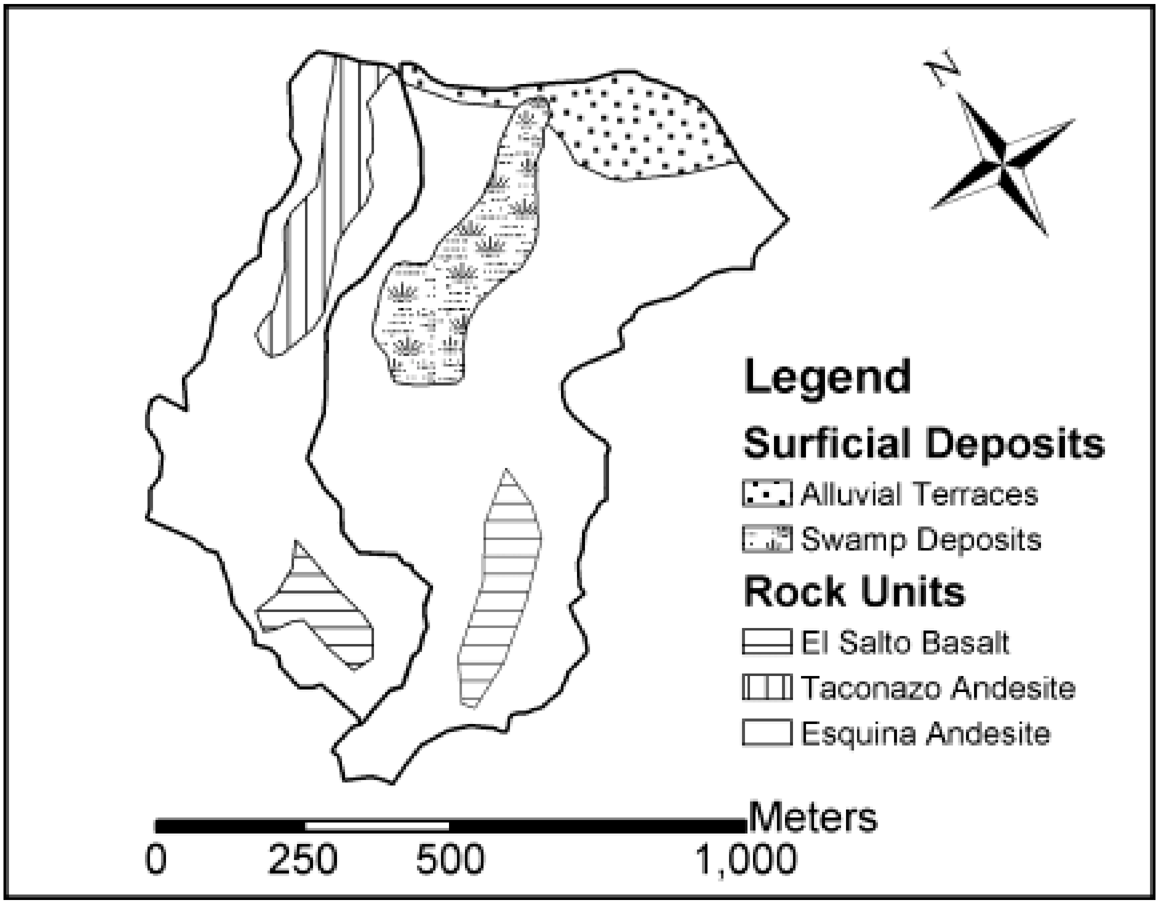


Figure 4. Rock types and swamp and terrace deposits of the Taconazo and Arboleda watersheds.

GIS coverage created by La Selva GIS Laboratory, OTS, based on maps presented in Alvarado 1990.

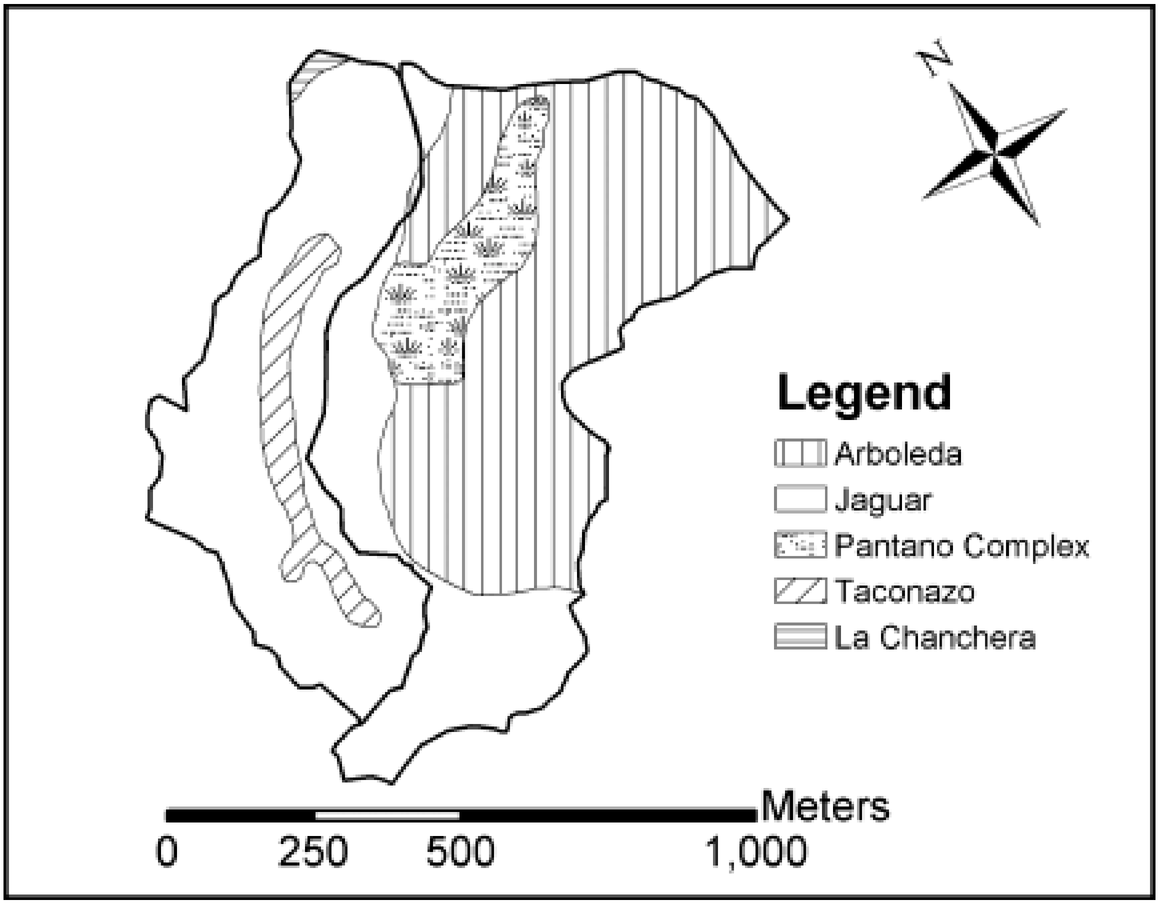


Figure 5. Soil types in the Arboleda and Taconazo watersheds.

GIS coverage created by La Selva GIS Laboratory, OTS, based on maps presented in Sancho and Mata 1987.

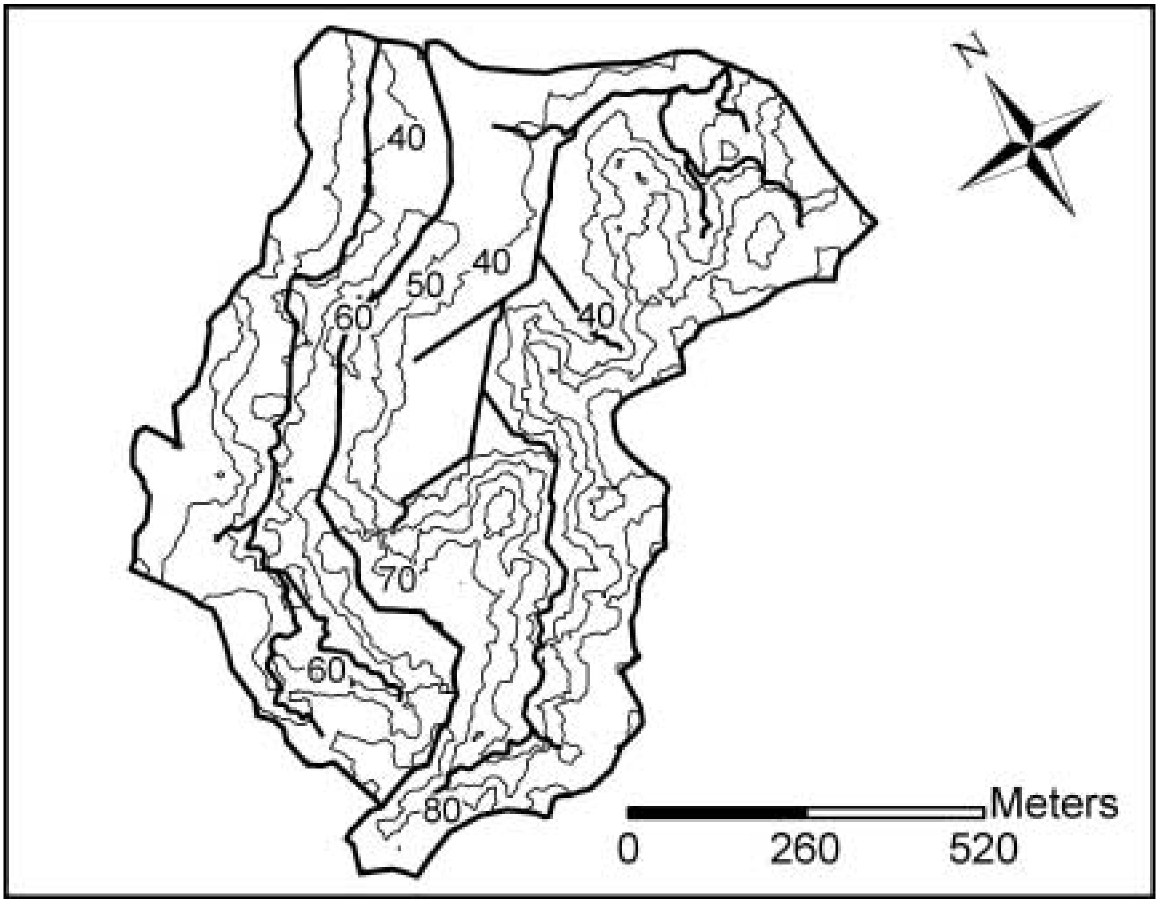


Figure 6. Topographic map of the Taconazo and Arboleda watersheds with a 10-meter contour interval.

GIS coverage created by La Selva GIS Laboratory, OTS.

Chapter 4: Water Budgets

4.1. Annual Water Budget Equations

Annual water budgets were calculated for four years (12/98-11/99; 12/99-11/00; 12/00-11/01; 12/01-12/02). The beginning and ending dates for the budgets were selected in an attempt to concentrate the majority of the gaps in the stream discharge data set into one budget year (12/99-11/00). The selection of a budget beginning on December 1 and ending on November 30 allowed for three budget years (12/98-11/99; 12/00-11/01; 12/01-12/02) with few stream discharge gaps.

The water budget equation for a "tight" watershed (one with no interbasin transfer) is:

$$\Delta S = P - ET - Q_S \qquad (4\text{-}1)$$

where ΔS is the change in storage, P is the rainfall, ET is the evapotranspiration, and Q_S is the stream discharge.

Based on our data presented below, it appears that the Taconazo watershed may be gaining a small amount of local water by IGT. To account for this, equation (4-1) needs to be modified to include this additional flux:

$$\Delta S = P + Q_{LI} - ET - Q_S \qquad (4\text{-}2)$$

where Q_{LI} is the IGT of local water into the watershed. All of the components in the equation were estimated directly based on data from the study site with the exception of Q_{LI}, which was calculated as a residual in equation 4-2. The uncertainty in the residual, Q_{LI}, was estimated as the quadratic sum of the uncertainties in each of the other terms in the water budget equation (Lesack 1993; Taylor 1982).

Previous work by Genereux et al. (2002) and additional preliminary budget calculations indicate that the Arboleda watershed receives IGT of both local water and bedrock groundwater (see section 3.8 and results to follow in Chapters 4 and 5). It is possible to calculate the IGT into the Arboleda in a similar manner to the Taconazo. But since the two waters, local water and bedrock groundwater, have distinct chemical signatures, it possible to go one step further by separating the two. Chloride data were used to separate the Arboleda IGT into local water and bedrock groundwater. The water budget equation for the Arboleda is:

$$\Delta S = P + Q_{GI} + Q_{LI} - ET - Q_{LS} - Q_{GS} \qquad (4\text{-}3)$$

where Q_{GI} is the input of high-solute bedrock groundwater by IGT, Q_{LI} is the input of low-solute local water to the watershed by IGT, Q_{LS} is the stream discharge of local water, and Q_{GS} is the stream discharge of bedrock groundwater. All of the terms in equation (4-3) were calculated or estimated based on measurements with the exception of Q_{LI}, which was calculated as the residual.

Note that the total stream discharge, Q_{GS}, is simply the sum of stream discharge of local water plus stream discharge of bedrock groundwater ($Q_S = Q_{LS} + Q_{GS}$). Q_S was calculated based on the stage (water level) at the weir, Q_{GS} was calculated using chemical data and stream export (as explained below), and Q_{LS} was calculated as the difference ($Q_{LS} = Q_S - Q_{GS}$).

Q_{GS} was calculated based on the stream discharge, Q_S, and chemical data. It was assumed that all of the IGT of bedrock groundwater into the watershed, Q_{GI}, leaves the watershed as stream flow, Q_{GS}. Thus, $Q_{GI} = Q_{GS}$. Q_{GS} was calculated by multiplying the total stream discharge, Q_S, by the fraction of stream water discharge that is bedrock groundwater, f_{GS}.

$$Q_{GI} = Q_{GS} = f_{GS} * Q_S. \quad (4\text{-}4)$$

f_{GS} was calculated based on a two end-member model for mixing of low-solute local water and high-solute bedrock groundwater:

$$f_{GS} = (C_S - C_L) / (C_G - C_L) \quad (4\text{-}5)$$

where C refers to the chloride concentration and the subscripts S, L, and G refer to streamwater, local water, and bedrock groundwater, respectively. The chloride concentrations needed for calculation of f_{GS} were obtained from chloride measurements as explained in section 4.6 (Results and Discussion).

Of the major cations and anions analyzed for in this study, chloride is the best one to use for the separation of local water from bedrock groundwater for this study. It is preferable to not use cations because they can undergo cation exchange whereas anions such as chloride are more conservative. Sulfate may sorb to oxides and be reduced, making it a less attractive choice in comparison to chloride (e.g., Johnson et al. 1979). It is also preferable to use chloride to separate the two end-member waters because chloride is representative of chemically evolved groundwater in a long flow system.

A typical anion evolution in groundwater along a long flow path is from HCO_3^- to SO_4^- to Cl^- (Kehew 2001). The chloride groundwater facies characterize regional flow systems. The increase in chloride concentration along a groundwater flow path depends on the presence of chloride in the aquifer. Studies have shown that an increase in chloride in andesitic-basaltic aquifers can occur from volatiles trapped in the glass or in vesicular basalt

(Edmunds et al. 2002). Chloride concentration, as well as Na, Ca, and K concentrations, generally increase with increased residence time in the volcanic bedrock.

4.2. Change in Groundwater Storage

Change in groundwater storage, ΔS, was estimated based on water levels in a series of eight shallow piezometers (Figure 7). Five of the eight piezometers are located in the Arboleda watershed with three being located downstream and two upstream. Three of the eight piezometers are located in the Taconazo watershed with two being located downstream and one being upstream. Measurements of depth to the water table were collected on a weekly basis from February 2000 to February 2001 and on a bi-weekly basis from March 2001 to September 2002 with one additional reading in January 2003 (Table 1).

Change in groundwater storage cannot be calculated for the first two budget years (12/98-11/99 and 12/99-11/00) due to the absence of groundwater data. The storage term was calculated for the last two budget years (12/00-11/01 and 12/01-11/02) for each watershed. For each watershed, the change in storage was calculated for the upstream and downstream areas separately by multiplying the average change in groundwater depth over the year by the watershed area (either upstream area or downstream area) and an estimate of the specific yield (the portion of porosity that can drain by gravity). The upstream and downstream totals were added together giving a value for change in storage in mm of water (Table 1).

The area of the upstream and downstream portions of each watershed was determined using the cut and weigh method (Table 1). In each watershed, the division between the upstream and downstream portions was chosen to be approximately half-way between the upstream and downstream well sites. An estimate for the specific yield (Table 1) was made based on soil textural information from the study site (Sollins et al. 1994; Sancho and Mata 1987; Bourgeois et al. 1972) and general information on the relationship between soil texture and specific yield (Johnson 1967).

The change in storage calculated for the Arboleda watershed was –20 mm and +26 mm for budget years of 12/00-11/01 and 12/01-11/02, respectively. For the Taconazo, the values were –33mm in 12/00-11/01 and +42mm in 12/01-11/02. A change in groundwater storage of this magnitude represents less than one percent of the annual rainfall. The change in groundwater storage is considered to be trivial in terms of the water budgets for the study watersheds, especially when compared to the fluxes (and their uncertainties) in the water budget calculation. Thus, ΔS was taken to be zero for all budget years.

4.3. Rainfall

Rainfall, P, is continuously recorded with a tipping bucket rain gauge (Qualimetrics 6011-B) in a clearing about 900 meters from the outlets of the study watersheds (Figure 8). The gauge is operated by the Organization for Tropical Studies (OTS). Continuous rainfall data from the gauge are aggregated into hourly and daily totals; data are available from the La Selva website (*www.ots.ac.cr/en/laselva/*). A manual rain gauge is also located at the same site and is used to confirm the tipping bucket rain gauge data. OTS tipping bucket and manual data were summed for the length of each budget year (Table 2). Annual totals from the two gauges were very similar, and the tipping bucket data were used in the budget calculations.

During November 1999, a nonconsecutive 5-day gap occurred in the OTS tipping bucket rainfall data set. To repair the gap, rainfall data collected by the Carbono Project on a 30-meter tower were used. Over those 5 days, using the Carbono data set, the total amount of rain that fell was compared with the Carbono monthly total (i.e., on November 3, 4, 5, 7, and 14, Carbono tower recorded 159.5 mm compared to a monthly total of 232.0 mm for a percentage of 69%). The OTS rain data set was then adjusted by adding the proportion of rain that fell based on the Carbono data (i.e., [OTS total w/ gap for 11/99] + 0.69 x [new OTS total for 11/99] = [new OTS total for 11/99]).

The average annual rainfall recorded during the four-year long budget study was 4974 mm, which is well above the long-term average of 4,242 (based on OTS data from 1958 through 2002). The recorded rainfall varied from a low of 4,281 mm during the 12/00-11/01 budget year to a high of 5,706 mm during the 12/01-11/02 budget year. The last budget year (12/01-11/02) had the second highest rainfall total ever recorded at La Selva compared to calendar year averages dating back to 1958.

Winter (1981) estimates that errors in rainfall measurements are approximately 4 percent at a measurement device density of one per 2.6 km^2. The error increases to 10 percent at a density of one measurement device per 21 km^2 (Winter 1981). The experimental results of Williams and Melack (1997) were in agreement with Winter's theoretical estimates. Rainfall data that was collected by OTS using an automatic tipping bucket rain gauge and a manual gauge, which was read daily, were found to be within 1.5 percent of one another over the four budget years. The tipping bucket rain gauge at La Selva has an accuracy of 0.5 percent for low rainfall rates (<12 mm/hr) and a decreasing accuracy with heavier rainfall events. Winter's (1981) estimates of rainfall error were adapted for the present study by drawing two circles (2.6 and 21 km^2 in area) with the centers positioned at the location of the OTS tower where rainfall data is collected. The Taconazo and Arboleda watersheds fall outside of the 2.6 km^2 circle and inside the 21 km^2 circle. Thus, uncertainty in the annual rainfall inputs to the study watersheds are expected to be approximately 7 percent (mid-way between 4 and 10 percent). Uncertainties in rainfall ranged from a low of 300 mm (12/00-11/01) to a high of 399 mm (12/01-11/02).

4.4. Stream Discharge

Stream discharge, Q_S, was calculated based on stage height data recorded at a 90-degree V-notch weir at the outlet of the Taconazo watershed and a 120-degree V-notch weir at the outlet the Arboleda watershed (Figure 7). Stage height was measured in 10-minute intervals from December 1998 to December 1999. Beginning in January 2000 through the end of the study in December 2002, stage height was measured in 15-minute intervals. Stage height was recorded using a stilling well that contains a float-pulley-counterweight arrangement with a shaft encoder and data logger. The stream discharge (in m^3/min) was calculated based on a relationship with the water level (in m) in the stilling well (Rantz et al. 1982). For the 90-degree V-notch geometry at the Taconazo, the relationship is:

$$Q_S = 81.82 \text{ (stage height)}^{2.5}. \qquad (4\text{-}6)$$

The stage-discharge relationship at the Arboleda with the 120-degree V-notch weir is:

$$Q_S = 144.1 \text{ (stage height)}^{2.5}. \qquad (4\text{-}7)$$

The instantaneous stream discharge calculated from equations (4-6) and (4-7) was multiplied by the appropriate time interval (10 or 15 minutes) to determine the volume of water discharged every 10 or 15 minutes from each weir. These volumes were then summed to give the total volume of stream discharge at each weir, for each budget year. In order to convert the annual stream discharge from units of volume (m^3) to units of height (mm), the volumetric discharge was divided by the area of the watershed and a conversion factor.

Gaps in the stream flow data set occurred several times during the study period due to "backflooding" events and equipment malfunctions (Appendix 4). Backflooding occurs due to large, rapid rises (up to a few meters in a few hours) of the Rios Sarapiqui and Puerto Viejo in response to heavy rainfall in upstream watersheds. This backflooding sometimes completely floods the weirs under a few meters of water; in this condition the weir cannot be used to determine discharge from the watershed. Even smaller backflood events, where the water level on the downstream (tailwater) side of the weir rises to the level of the V-notch in the weir, are sufficient to prevent accurate estimation of stream discharge with the weir rating equation. When this occurs, the stream discharge cannot be calculated because the stage-discharge relationship for the weir is no longer valid.

Different gap fill methods were developed to be used when the stream discharge cannot be calculated from the stage height data. For short gaps (< 0.5 days, Appendix 4), the "straight-line" method was employed. The stream discharge that occurred during the gap was estimated by averaging the last valid stream discharge value before the gap began and the first valid value after the gap ended. The majority of the remaining gaps (i.e., those > 0.5 days) occurred in the range of 0.5 days to 2.5 days or over 7 days (Table 3, Figure 9, Appendix 4). Two regressions were developed for each watershed: one to estimate stream discharge for short gaps (0.5 days to 2.5 days) and another to estimate discharge for long gaps (> 1 week); a multi-regression tool for Excel was used (Myerson 2000). There were a few gaps that fell in between 2.5 days 7 days. For gaps less than 4 days in length, the short-gap regression was used.

Three of the regressions were developed based on rainfall during the gap and rainfall during three different time periods immediately preceding the gap. The fourth regression, which was used for short gaps on the Taconazo, was based on rainfall during the gap and stream discharge preceding the gap. Each regression was constructed using data from approximately 20 blocks of time during which stream discharge, rainfall, and antecedent rainfall where all known (Appendix 5-8). Several different scenarios were tested by varying the duration and number of antecedent rainfall blocks or by varying antecedent stream discharge blocks in to order determine which regression gave the best fit.

For the Taconazo short-gap regression, 10 different scenarios were attempted giving r^2 values of 0.015 to 0.757. The regression with an r^2 of 0.757 (Appendix 5) was based on (1) rainfall during the gap (2) and stream discharge 6 hours before the gap. Four different options were considered for the Taconazo long-gap regression with r^2 values of 0.836 to 0.885. The regression with an r^2 of 0.885 (Appendix 6) was based on (1) rainfall that occurred during the gap (2) rainfall that occurred 1-15 days before the gap (3) rainfall 16-35 days before the gap (4) and rainfall 36-60 days before the gap.

The most successful regression to estimate stream discharge for the Arboleda short gaps (Appendix 7) is based on (1) rainfall that occurred during the gap (2) rainfall that occurred 0-5 days before the gap (3) rainfall 6-10 days before the gap (4) and rainfall 11-20 days before the gap. It was chosen out of 10 different scenarios with r^2 values ranging from 0.513 to 0.617. A total of 4 possible options were tried for the Arboleda long-gap equation with r^2 values between 0.685 and 0.769. The best results (Appendix 8) were achieved using a regression based on (1) rainfall that occurred during the gap (2) rainfall that occurred 1-15 days before the gap (3) rainfall 16-35 days before the gap (4) and rainfall 36-60 days before the gap.

It should be noted that in a few instances, the regressions could not be computed due to missing antecedent rainfall data (or due to missing stream discharge data for the Taconazo short gaps) (Appendix 4). Gaps in the Arboleda data set that couldn't be filled using the regression equations occurred 5 times and varied in length from 0.63 days to 0.93 days. One gap that was 0.54 days long occurred in the Taconazo data set that could not be filled with the equations. In these instances, the straight-line method was employed to fill in the missing stream discharge data.

The stream discharge from the Taconazo watershed was 3,032 mm, 2,502 mm, 2,931 mm, and 4,312 mm in 12/98-11/99, 12/99-11/00, 12/00-11/01, and 12/01-11/02, respectively. The stream discharge from the Arboleda watershed was 12,632 mm, 12,412 mm, 12,436 mm, and 13,812 mm for the same four budget years, respectively. The stream discharge from the Arboleda is over 9,000 mm higher than the Taconazo due to IGT.

The expected error for measurement of annual discharge using a calibrated weir and water level recorder is typically less than 5 percent (Williams and Melack 1997; Lesack and Melack 1995; Lesack 1993; Winter 1981). Based on these literature results, 5 percent was taken as the uncertainty in the measurement of stream discharge, Q_S, for this study. Uncertainties varied from a low of 621 mm (12/99-11/00) to a high of 691 mm (12/01-11/02) for the Arboleda and a low of 125 mm (12/99-11/00) to a high of 219 mm (12/01-11/02) for the Taconazo. The uncertainty in Q_S for the Arboleda was further broken down into the uncertainties in Q_{GS} and Q_{LS}. The error in the stream export of bedrock groundwater, Q_{GS}, is a function of Q_S and the fraction of stream discharge that is due to bedrock groundwater, f_{GS} (Appendix 9). Uncertainty in Q_{GS} was between 150 mm (12/00-11/01) and 184 mm (12/98-11/99). Uncertainties in Q_{LS} and Q_{LI} (Table 5) were between 639 mm and 898 mm, and were calculated as explained in Appendix 9.

4.5. Evapotranspiration

The parameters needed to calculate evapotranspiration were not measured as a part of this study. Several previous studies at La Selva have made the required measurements and were able to estimate evapotranspiration (Loescher 2002; Parker 1985; Luvall 1984).

Parker (1985) and Luvall (1984) estimated evapotranspiration using the Penman-Monteith equation while working on studies that examined the effects of deforestation. Loescher (2002) calculated evapotranspiration using the Priestly-Taylor approach as well as Penman-Monteith. The result of Loescher's work indicates that the Priestly-Taylor equation is a more accurate way to estimate evapotranspiration at La Selva than the Penman-Monteith equation. The Priestly-Taylor equation is believed to be better suited for La Selva due to the well-watered canopy and humid conditions (Loescher 2002; Dingman 2002; Rosenberg et al. 1983; Priestly and Taylor 1972).

Several different approaches were used in this work to estimate annual evapotranspiration by adapting the results of the previous work at La Selva (Table 4). The first attempt utilized the Priestly-Taylor equation (Priestly and Taylor 1972):

$$\lambda E_P = \alpha(R_n) [\Delta / (\Delta + \gamma)] \qquad (4\text{-}8)$$

where λE is latent energy flux, α is an empirical coefficient, R_n is net radiation, Δ is the rate of increase in saturated water vapor pressure with temperature, and γ is the psychometric constant. The values of Δ and γ were determined based on the average annual temperature of

25 ^{o}C at La Selva (Sanford et al. 1994). Loescher (2002) experimentally determined α to be 1.24. The psychometric constant, γ, is 0.0665 kPa/K at 25 ^{o}C (Loescher 2002). The rate of increase in saturated water vapor pressure, Δ, at 25 ^{o}C is 0.196 kPa/K (Lide 1994). The constants in the equation (α, Δ, and γ) reduce to a value of 0.926 simplifying the Priestly-Taylor equation to:

$$\lambda E_P = 0.926(R_n) \qquad (4\text{-}9)$$

Because net radiation data was not available during the current study, it was estimated using a ratio of total solar radiation (TSR) data available from OTS to net radiation presented by Luvall (1984):

$$R_n = 0.94 \text{ (TSR)} \qquad (4\text{-}10)$$

This approach to estimating net radiation using the OTS TSR data resulted in estimates of evapotranspiration that were significantly lower than the Priestly-Taylor estimates reported by Loescher (2002) (Table 4). For this reason, this approach is thought to give poor estimates of annual evapotranspiration.

Rather than calculate evapotranspiration using the Priestly-Taylor or Penman-Monteith equations, many water budget studies determine it as a residual ($ET = \Delta S + Q_S - P$) from the water budget equation. This approach requires that the water budget be tight without any groundwater inflow or outflow from the watershed. While the Arboleda is not tight (Genereux et al. 2002), it is possible that the Taconazo watershed may be tight. The estimates of evapotranspiration based on the Taconazo watershed being tight were also much lower than those from Loescher (2002), probably because the watershed was receiving an

IGT of local water (see section 4.6). Without independent knowledge of the quantity of IGT, this approach cannot be used to calculate evapotranspiration.

Evapotranspiration was also estimated based on a relationship with rainfall. Luvall estimated that annual evapotranspiration at La Selva is approximately equal to 47 percent of rainfall. The ratio of evapotranspiration to rainfall found by Loescher (2002) over three years at La Selva varied from 0.48 to 0.50 (note: this ratio is based on Loescher's ET results and daily rain data obtained from OTS). The results of Luvall (1984) and Loescher (2002), as well as Parker (1985), at La Selva are comparable to results found in Amazonian tropical forests by Shuttleworth (1988) and Calder (1986) (Figure 10). A regression was developed to predict annual evapotranspiration based on annual rainfall (Figure 10). The regression shows little scatter and seems to have predictive ability, but was not used for theoretical reasons.

Shuttleworth (1988) suggests an increase in evapotranspiration can occur due to an increase in the interception of rainfall while a decrease in evapotranspiration may occur due to soil moisture deficits during years with less rainfall. This line of reasoning is likely true for a number of locations, but may not be valid for La Selva. La Selva receives approximately twice as much rain as does the Amazon location where the Shuttleworth study was undertaken (Shuttleworth 1988; OTS). As a result, water is not expected to be a limiting factor on evapotranspiration at La Selva. Additionally, it is not preferable to estimate evapotranspiration as a percentage of rainfall because it means that the rainfall and evapotranspiration terms in the water budget equation are no longer independent of one another. Though evapotranspiration is not limited by water in places with abundant rainfall, it is limited by the amount of available energy (Dingman 2002). Loescher (2002) found this to be true at La Selva where most of the inter-annual variability in evapotranspiration was accounted for by variations in net radiation.

A regression was developed to predict evapotranspiration based on its relationship with radiation (Figure 11). The regression was developed using three annual evapotranspiration values determined by Loescher (2002) and values for total solar radiation (TSR) measured by OTS during the corresponding years. TSR was measured in megajoules (MJ) using a Li-cor LI-200SZ pyranometer in conjunction with a data logger that records half-hour and daily totals. TSR values in MJ were converted to mm of water based on the latent heat of vaporization of water at 25 ^{O}C (43.990kJ/mol, Lide 1994), the density of water at 25 ^{O}C (997.044 kg/m^3, Fetter 2001), and the molar mass of water. The pyranometer measures both incident short-wave (i.e., solar) and long-wave (i.e., sky or atmospheric) radiation (*www.licor.com*). The daily TSR totals were summed to get annual totals. Gaps in the TSR data set were repaired using a relationship (TSR = PAR/2) between TSR and photosynthetically-active radiation (PAR) that is measured with a Li-cor LI-190SZ quantum sensor. TSR and PAR are measured at a height of 3 meters above the ground surface near the OTS tower (Figure 8).

The regression using TSR is expected to give accurate evapotranspiration estimates due to a constant albedo (the reflected and absorbed portions of incident radiation do not exhibit a temporal variation) and a small sensible heat flux (almost all absorbed radiation is lost as evapotranspiration) at La Selva (Loescher 2002). The regression equation was used to calculate evapotranspiration values of 2,345 mm, 2,141 mm, 1,961 mm, and 1,961 mm for budget years 12/98-11/99, 12/99-11/00, 12/00-11/01, and 12/01-11/02, respectively. The uncertainty in these estimates of annual evapotranspiration is based on the regression equation and a confidence interval of 70 percent (Appendix 9). Uncertainty in evapotranspiration ranged from a high of 345 mm (15 percent) to a low of 225 mm (11 percent). The estimates of evapotranspiration seem reasonable in comparison with previous evapotranspiration measurements of 2063 mm by Luvall (1984) and 2210 mm by Parker (1985) at La Selva.

4.6. Results and Discussion

The water budget equations presented in Section 4.1 were used to calculate the annual water budgets for each watershed. The results of the water budgets for each watershed were summarized in monthly tables (Appendix 10), an annual table (Table 5), and annual stacked bar charts (Figures 12-15).

The annual Taconazo budgets were computed using equation 4-2 and the hydrologic flux values presented in Sections 4.2-4.5. Annual water budgets for the Arboleda watershed were computed using Equations 4-3 to 4-5, the hydrologic flux values presented in Sections 4.2-4.5, and chloride data which was needed for equation 4-5. Equation 4-5 requires Cl data for 3 waters: local water, bedrock groundwater, and Arboleda stream water at the weir (the "Arbo" sampling site).

The chloride concentration of local water was defined by averaging concentrations measured in nearly 900 water samples collected from the seven lowest-concentration sites (Arbo4, Taco, Taco8, well 4, well 6, well 7, and well 8) (Table 6, Figure 7). These seven sampling sites consistently had the lowest solute concentrations. Samples from the same sites were also used to define the average SO_4, Na, K, Mg, and Ca concentrations of the local water end-member (Table 6). The end-member concentrations of these additional ions were needed for the chemical budget work described in Chapter 5.

Average concentrations of Cl and other major ions in the bedrock groundwater end-member were based on approximately 150 water samples from Guacimo Spring, the site with the highest major ion concentrations in the area (Table 6). Guacimo Spring is a large spring located on the northwest bank of the Guacimo River approximately 1.5 km southeast of La Selva. A large concrete culvert is designed to capture the spring water. From the culvert, the spring water is piped as a potable water source to the nearby town of Puerto Viejo de Sarapiqui (it does not undergo any type of treatment). Samples of the spring water were collected from three faucets connected to the potable water system in Puerto Viejo de Sarapiqui, as well as being directly sampled at the spring source (Guacimo Spring). Samples were originally collected from a faucet located inside a house ("Papillo House", 12/2/98-7/28/00). Due to access restrictions, it became necessary to collect samples from a faucet located outside of the house ("Papillo Outside", 6/23/00-3/23/01, 7/13/01-8/24/01). Access to the outside of the house was restricted after the construction of a fence. Sampling then moved across the street from the house to the Red Cross building ("Red Cross", 3/9/01-11/28/02). The samples from all four sites (Guacimo Spring and the three faucets in Puerto Viejo de Sarapiqui) had comparable concentrations of major ions. Samples were collected on a monthly basis from December 1998 through December 1999 and on a weekly basis from February 2000 through November 2002.

The concentration of Cl at the Arbo site, which is needed for Equation 4-5 to determine f_{GS}, was determined using two different approaches. Arboleda water budgets from the two approaches were then compared for an arbitrary 12-month period, 3/00-2/01 (not one of the four budget years). The "weekly approach" calculates f_{GS} using the Cl concentration measured in each weekly sample as the value for C_S. The f_{GS} value was multiplied by the volumetric stream discharge for a week centered on the time of the sample collection (Equation 4-4). The additional terms on the right hand side of Equation 4-3 other than P and ET (i.e., Q_{GI}, Q_{LI}, and Q_{LS}) were also computed on a weekly basis and annual values were obtained by summation of the weekly values.

The "regression-based approach" used a regression to predict Cl based on stream discharge. A regression equation (Cl (mM) = 0.035 + 3.6728/Qs, r^2 = 0.82) was developed using stream discharge and Cl data collected from 3/00 to 2/01 (Figure 16). This equation was used with Arboleda stream discharge data collected every 15 minutes to estimate Arbo Cl concentration every 15 minutes during 3/00-2/01. The 15-minute predicted Cl values were used in Equation 4-5 to compute f_{GS} on a 15-minute basis. The additional terms other than P and ET on the right hand side of Equation 4-3 (Q_{GI}, Q_{LI}, and Q_{LS}) were then also computed on a 15-minute basis and summed to obtain annual values.

The regression-based approach gave Q_{GS} and Q_{GI} values that were 8 percent lower than the weekly approach for the 3/00-2/01 test year. The difference between the two approaches is due to the fact that the weekly approach is controlled by Cl samples collected at baseflow conditions when chloride concentrations are higher. The weekly approach implicitly assigns relatively high Cl concentrations to high flows, which Figure 16 suggests is not accurate. Thus, it tends to over predict the amount that bedrock groundwater contributes to stream discharge. The regression-based approach allows for a more accurate calculation of the contributions of bedrock groundwater and local water to stream discharge, and was used in calculation of water budgets for the Arboleda watershed (Table 5, Figures 12-15).

To apply the regression-based approach to calculation of Arboleda water budgets for the four budget years, a regression (Figures 17-18) was developed using the stream discharge data and weekly Cl measurements during the four budget years (12/98 – 11/02) and additional storm sampling in June and July 2002 (Figure 19). Nine samples, which were collected during backflooded conditions, were removed from the data set. Six outlier samples were observed with lower than expected chloride concentrations based on the stream discharge at the time they were sampled. The regression was developed both with and without the outlier samples to determine the effect of the outliers on the equation. Because the removal of the outlier samples from the data set had a negligible effect on the regression equation, the samples were included in the data set.

The most noticeable outcome of the water budgets was the difference in stream discharge between the two watersheds that resulted from IGT into the Arboleda watershed. The Arboleda watershed receives a significant quantity of bedrock groundwater from the discharge of IGT. The discharge of bedrock groundwater in the Arboleda watershed was relatively constant on both monthly and annual time scales, averaging 4,367 mm of water over the four budget years with a difference of only 96 mm of water between the highest (12/99-11/00) and lowest (12/01-11/02) years. The steady discharge of bedrock groundwater is consistent with the idea of groundwater discharge from a deep, regional groundwater system. The discharge of local water from the Arboleda watershed was more variable, ranging from a low of 8,000 mm of water (12/99-11/00) to a high of 9,496 mm of water

(12/01-11/02). It is important to note that the IGT of local water could not be detected through the use of chemical data alone. In order to detect and quantify local water IGT, the chemical data in combination with the hydrologic data was needed.

Together, the IGT of local water and bedrock groundwater cause the Arboleda to have approximately three times the water flux in and out of the watershed when compared to the Taconazo. The Taconazo does not have any indication of bedrock groundwater IGT discharging in the watershed. However, it is likely that the watershed receives a small amount of local water IGT. Three of the four budget years (all except 12/99-11/00) indicate a small (159 mm to 588 mm) amount of local water IGT into the watershed. Though this amount is within the uncertainty in the annual budget, there may be a small interbasin transfer of local water into the watershed. The 12/99-11/00 budget year indicates a groundwater loss of approximately 45 mm in the Taconazo watershed. The 45 mm of water is well within the error range of the other components and is not considered significant. Also, for the Taconazo, a long gap in measured stream flow caused the water budget for this year to be more uncertain than for the other three years.

The Arboleda discharge is greater than the Taconazo both in terms of local water and in terms of bedrock groundwater. The Arboleda stream discharge is typically composed of slightly more local water than bedrock groundwater. In exceptionally rainy months local water generally comprises an even larger percentage of the total stream discharge (Appendix 10). The stream discharge of the Taconazo stream is solely comprised of local water.

Table 1. Measurements of depth to groundwater and calculations for change in groundwater storage for the Taconazo and Arboleda watersheds

Change in Groundwater Storage for the Arboleda Watershed

	Water Depth Below Ground Surface (cm)					
	Downstream Wells			Upstream Wells		
Well No.	1	2	3	4	5	
12/01/00	63.80	13.30	129.40	3.40	49.20	Avg Downstream Δ: -12.50
12/06/01	37.70	11.80	119.50	0.10	24.10	Avg Upstream Δ: -14.20
Change	-26.10	-1.50	-9.90	-3.30	-25.10	
12/06/01	37.70	11.80	119.50	0.10	24.10	Avg Downstream Δ: 12.13
01/23/03	62.00	14.00	129.40	18.60	50.10	Avg Upstream Δ: 22.25
Change	24.30	2.20	9.90	18.50	26.00	

Specific Yield = 0.15
Upstream Area: 23.41 ha = 234,060 m^2
Downstream Area: 26.62 ha = 266,190 m^2

Budget	Change in Storage (mm)		
Year	Upstream	Downstream	Total Δ
12/00-11/01	-10	-10	-20
12/01-11/02	16	10	26

Change in Groundwater Storage for the Taconazo Watershed

	Water Depth Below Ground Surface (cm)			
	Downstream Wells		Upstream Well	
	6	7	8	
12/01/00	111.30	87.70	19.80	Avg Downstream Δ: -31.20
12/06/01	77.70	58.90	3.90	Avg Upstream Δ: -15.90
Change	-33.60	-28.80	-15.90	
12/06/01	77.70	58.90	3.90	Avg Downstream Δ: 33.65
01/23/03	112.00	91.90	27.80	Avg Upstream Δ: 23.90
Change	34.30	33.00	23.90	

Specific Yield = 0.15
Upstream Area: 16.05 ha = 160,480 m^2
Downstream Area: 10.31 ha = 103,136 m^2

Budget	Change in Storage (mm)		
Year	Upstream	Downstream	Total Δ
12/00-11/01	-15	-18	-33
12/01-11/02	22	20	42

Table 2. Comparison of annual rainfall amounts (in mm) based on data collected using a tipping bucket rain gauge and a manual gauge (OTS). Data for the 12/98-11/99 budget year were corrected as described in section 4.3

	Annual Rainfall	
Year	Tipping Bucket	Manual Gauge
12/98-11/99	5,219 ± 365	5,143 ± 360
12/99-11/00	4,688 ± 328	4,671 ± 327
12/00-11/01	4,425 ± 310	4,611 ± 323
12/01-11/02	5,706 ± 399	5,691 ± 398

Table 3. Number of gaps in the stream discharge data set for each watershed subdivided based on gap duration

Gap	**Number of Gaps**	
Length	**Arboleda**	**Taconazo**
< 0.5 day	14	20
0.5 - 2.5 days	24	10
> 2.5 days	7	8
Total	45	38

Table 4. Different approaches to estimate evapotranspiration for each budget year based on the results of previous evapotranspiration measurements made at La Selva

Year	ET^1	ET^2	ET^3	ET^4	ET^5
1998	1892	1649	no data	1923	1902
1999	2294	1988	1730	2300	2324
2000	2230	1877	2063	2171	2186

ET^1 ET estimates made by Loescher (2002) using the Priestly-Taylor equation

ET^2 ET estimates calculated with the Priestly-Taylor equation (Rn was approximated based on Rn = 0.94*TSR, from Luvall (1984))

ET^3 ET estimates based on the assumption that the Taconazo watershed is "tight"

ET^4 ET estimates based on the regression of ET vs. rainfall

ET^5 ET estimates based on the regression of ET estimates by Loescher (2002) vs. TSR measured by OTS

Table 5. Annual water budget components for the Arboleda and Taconazo watersheds

ARBOLEDA WATERSHED

INPUTS (mm)

Year	12/98-11/99	12/99-11/00	12/00-11/01	12/01-11/02
Rain	5,219± 365	4,688± 328	4,281± 300	5,706± 399
Q_{GI}	4,359± 184	4,412± 152	4,381± 150	4,316± 160
Q_{LI}	5,400± 868	5,454± 783	5,735± 791	5,772± 898
Total	14,978± 959	14,554± 862	14,397± 859	15,795± 996

OUTPUTS (mm)

Year	12/98-11/99	12/99-11/00	12/00-11/01	12/01-11/02
ET	2,345± 345	2,141± 225	1,961± 323	1,983± 304
Q_{GS}	4,359± 184	4,412± 152	4,381± 150	4,316± 160
Q_{LS}	8,273± 658	8,000± 639	8,055± 640	9,496± 709
Total	14,977± 765	14,553± 694	14,397± 732	15,795± 788

TACONAZO WATERSHED

INPUTS (mm)

Year	12/98-11/99	12/99-11/00	12/00-11/01	12/01-11/02
Rain	5,219± 365	4,688± 328	4,281± 300	5,706± 399
Q_{GI}	0	0	0	0
Q_{LI}	159± 525	-45± 417	611± 465	588± 546
Total	5,377± 639	4,642± 531	4,892± 553	6,295± 676

OUTPUTS (mm)

Year	12/98-11/99	12/99-11/00	12/00-11/01	12/01-11/02
ET	2,345± 345	2,141± 225	1,961± 323	1,983± 304
Q_{GS}	0	0	0	0
Q_{LS}	3,032± 152	2,502± 125	2,931± 147	4,312± 216
Total	5,377± 377	4,642± 257	4,892± 355	6,295± 373

Table 6. Local water and bedrock groundwater end-member concentrations (Conc), standard deviations (SD), coefficients of variation (CV), and number of samples (n) for major anions and cations

Local water consists of samples collected at Arbo4 (weekly, 02/06/00-11/28/02), Taco (weekly, 12/01/98-11/28/02), Taco8 (weekly, 02/14/02-11/28/02), and wells 4, 6, 7, and 8 (anions: weekly, 02/06/00-02/15/01 and bi-weekly, 2/15/01-09/26/02; cations: bi-weekly, 2/15/01-09/26/02). Bedrock groundwater consists of samples collected monthly at Papillo (12/02/98-12/02/99) and weekly at Papillo/Guacimo Spring/Red Cross (02/22/00-11/28/02).

Solute	Local Water				Bedrock Groundwater			
	Conc	SD	CV (%)	n	Conc	SD	CV (%)	n
Cl (mM)	0.0634	0.0129	20	961	0.9100	0.0203	2	158
SO_4 (mM)	0.0027	0.0022	79	967	0.0416	0.0019	5	145
Na (mM)	0.0655	0.0207	32	833	1.9095	0.0929	5	147
K (mM)	0.0090	0.0079	87	833	0.2368	0.0129	5	147
Mg (mM)	0.0124	0.0051	41	833	1.6126	0.0920	6	147
Ca (mM)	0.0122	0.0099	81	833	0.8679	0.0462	5	147

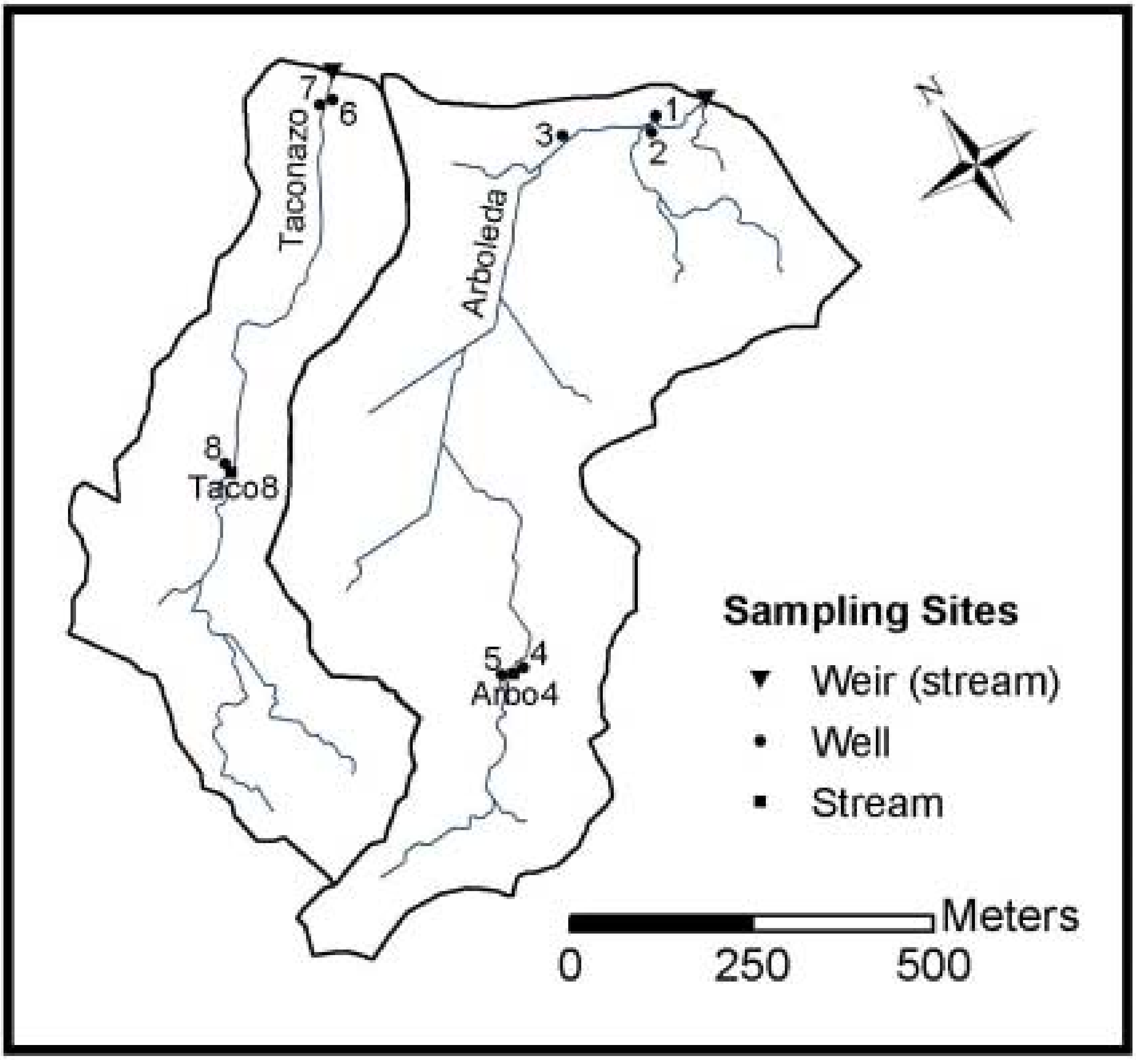


Figure 7. Location of sampling points in the Taconazo and Arboleda watersheds including the weirs, other stream locations (Taco8, Arbo4), and the wells (1-8).

GIS coverage created by La Selva GIS laboratory, OTS.

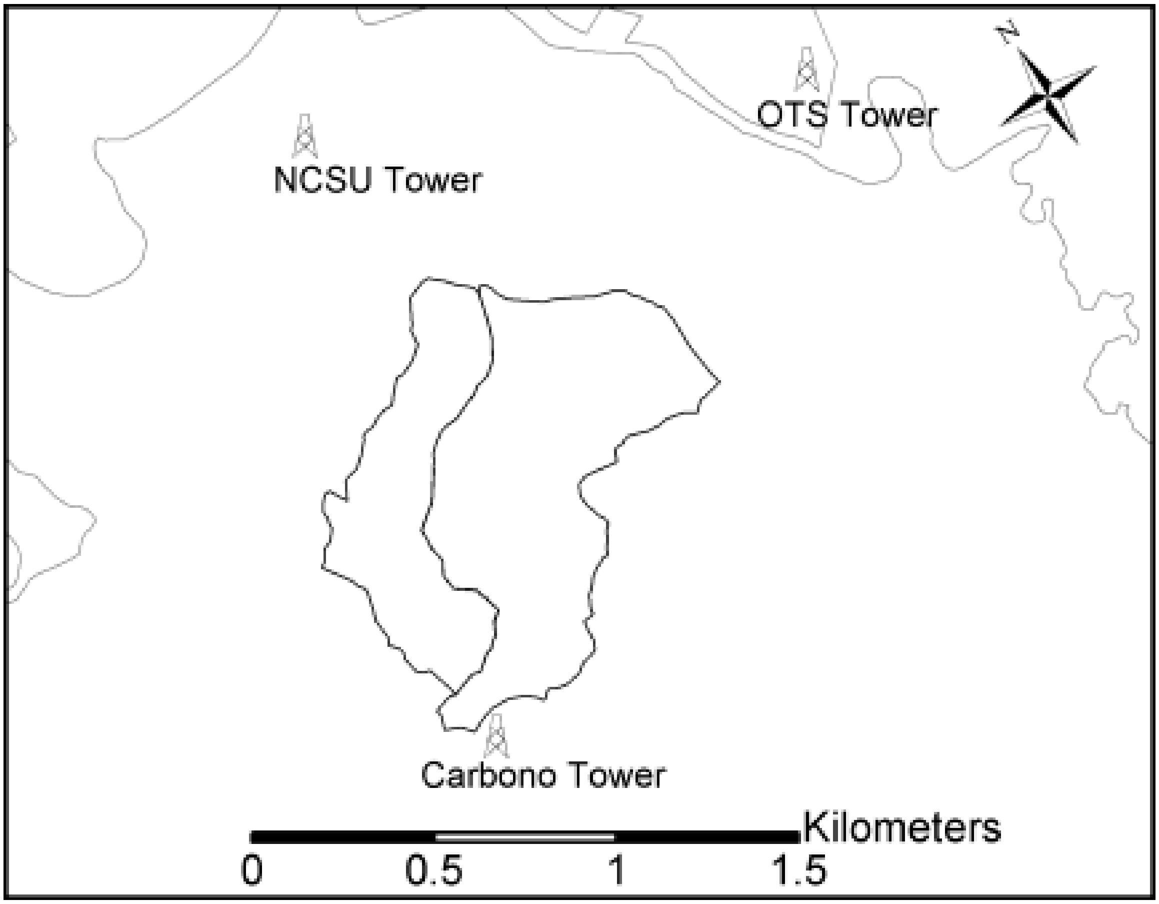


Figure 8. Location of the tipping bucket and manual rain gauge operated by OTS (OTS Tower), the bulk rainfall collector (NCSU Tower), and the meteorological tower operated by the Carbono Project (Carbono Tower) in relation to the study watersheds.

GIS coverage created by La Selva GIS laboratory, OTS.

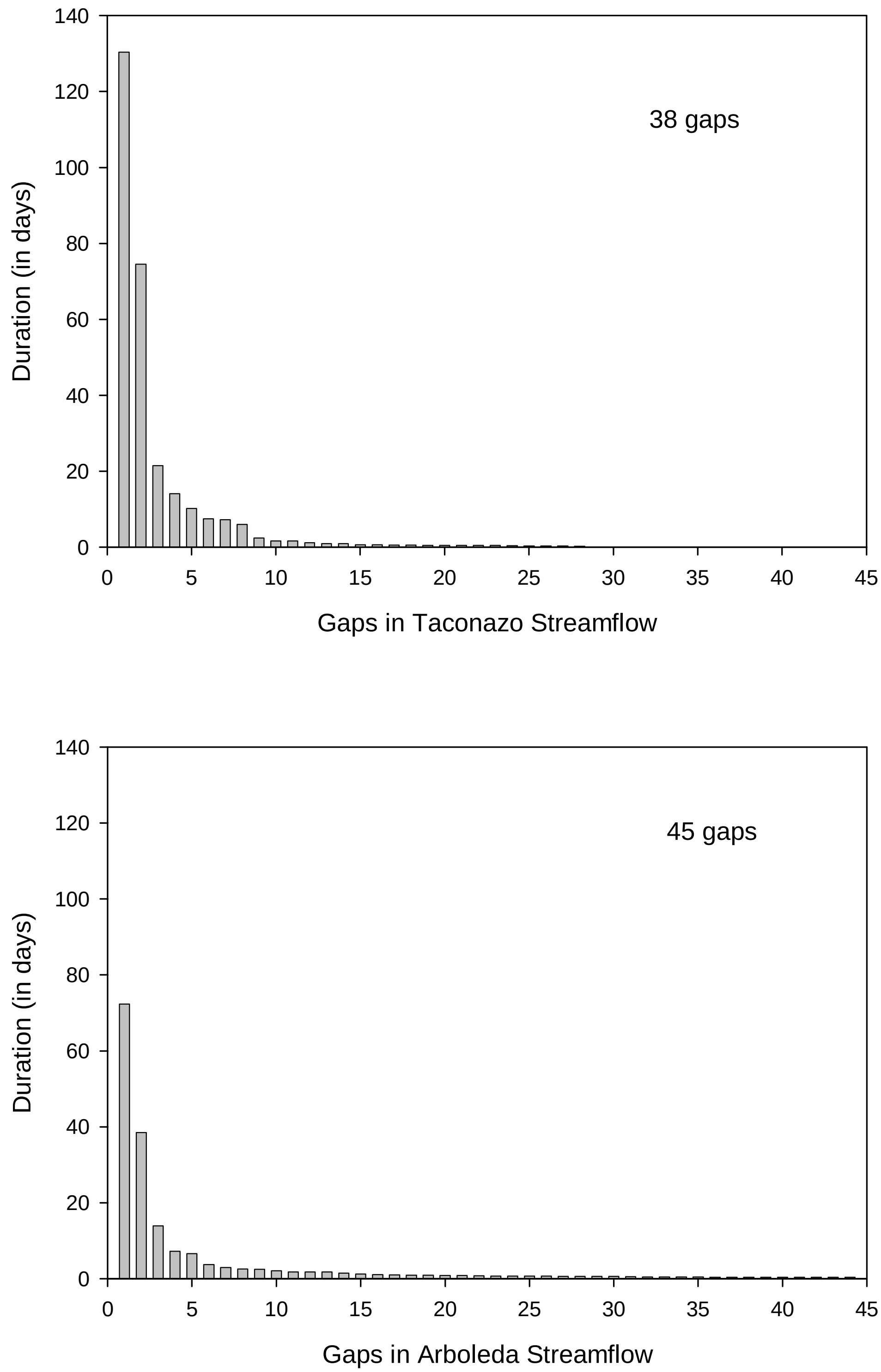


Figure 9. Duration of gaps (in days) in the streamflow data sets for the Taconazo and Arboleda watersheds.

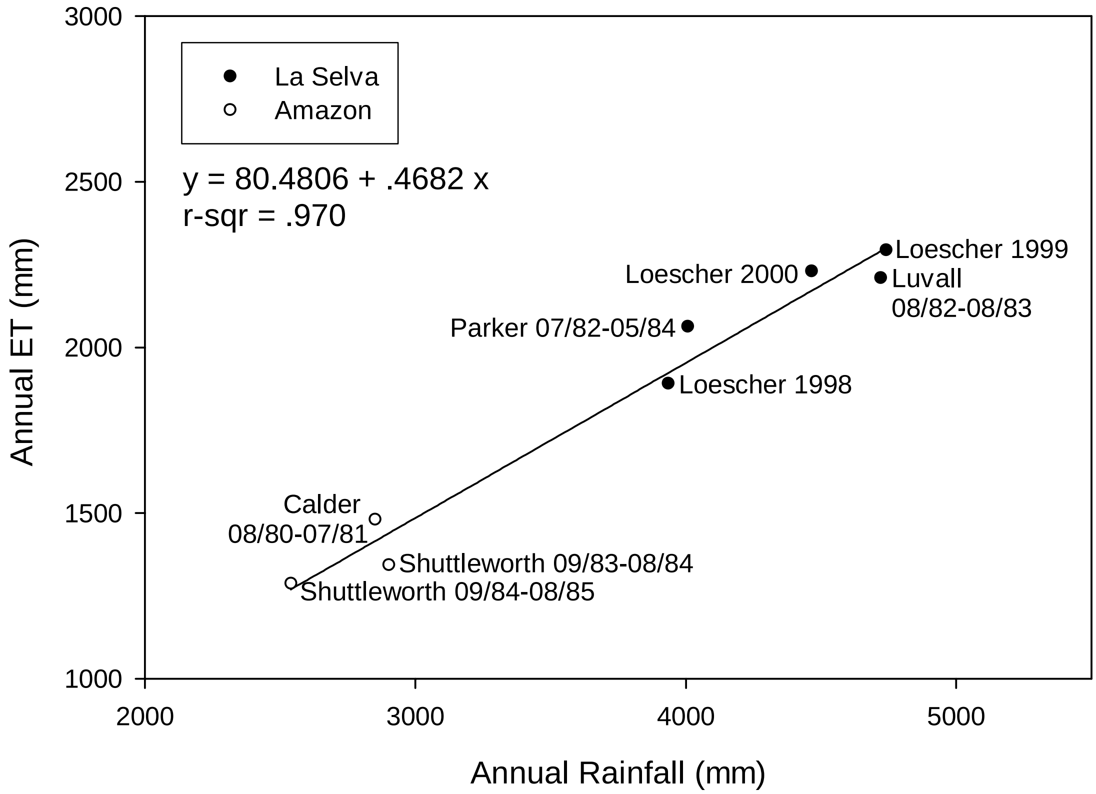


Figure 10. Evapotranspiration (in mm) versus annual rainfall (in mm).

Measurements made at La Selva are shown as solid circles and measurements made in tropical Amazonian forests are shown as open circles.

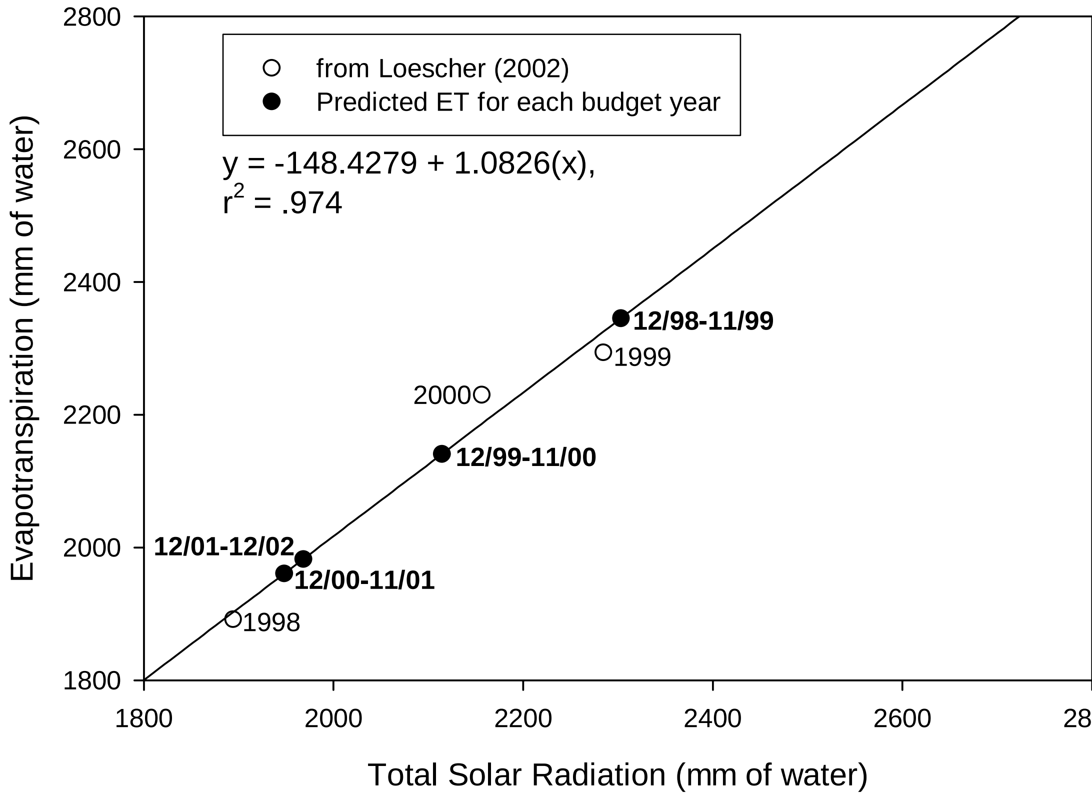


Figure 11. Evapotranspiration (in mm) versus total solar radiation (TSR) as measured by OTS.

TSR values were converted from energy units (MJ) to mm of water as explained in the text. The evapotranspiration values calculated by Loescher (2002) were used to construct the regression line and are shown as open circles. Evapotranspiration values that were predicted for each budget year using the regression line shown are solid circles.

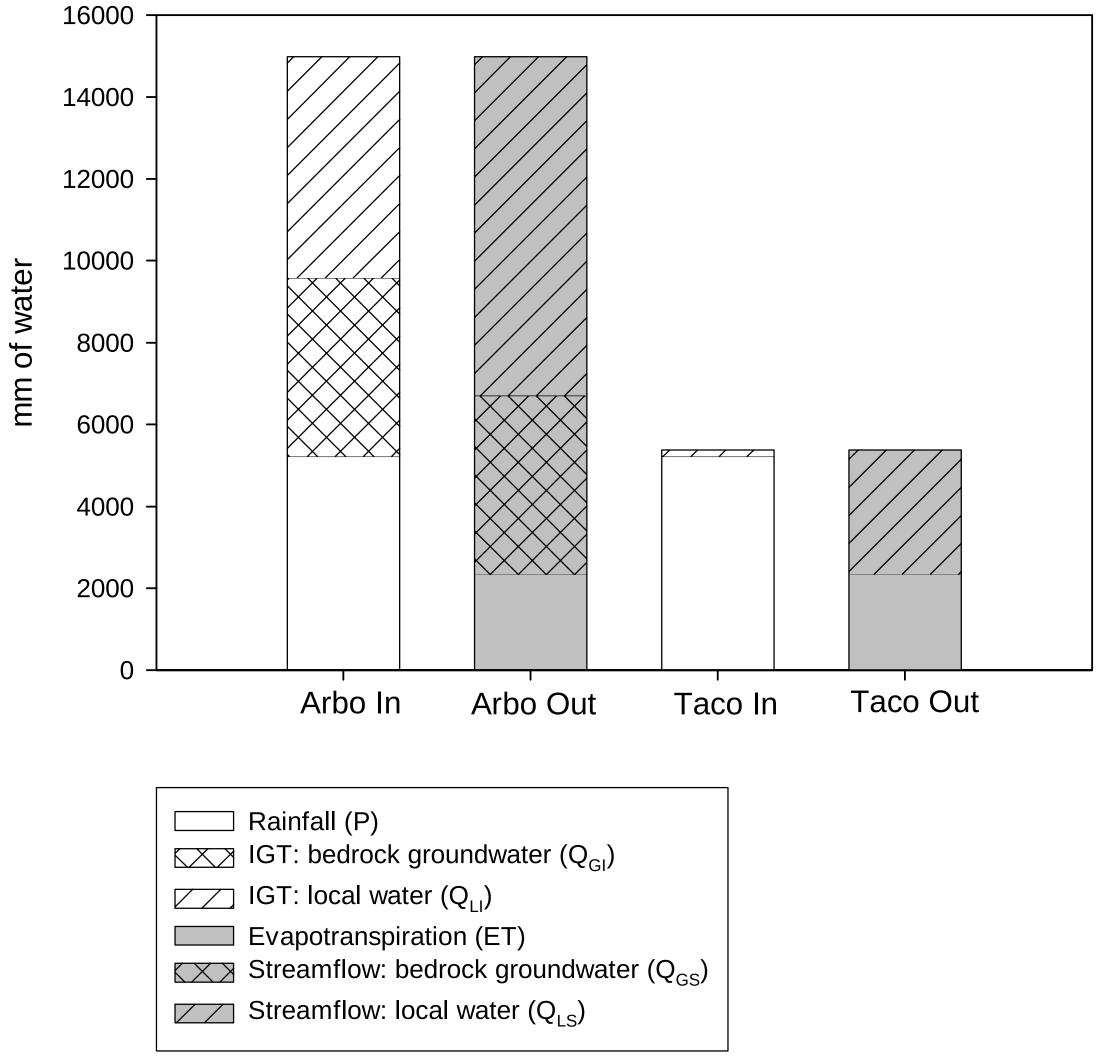


Figure 12. Annual water budget for the Taconazo and Arboleda watersheds for 12/98 to 11/99.

The inputs to the Arboleda and Taconazo watersheds are labeled Arbo In and Taco In, respectively. The outputs from the Arboleda and Taconazo watersheds are labeled Arbo Out and Taco Out, respectively. The inputs and outputs were normalized by the area of each watershed to allow for direct comparison.

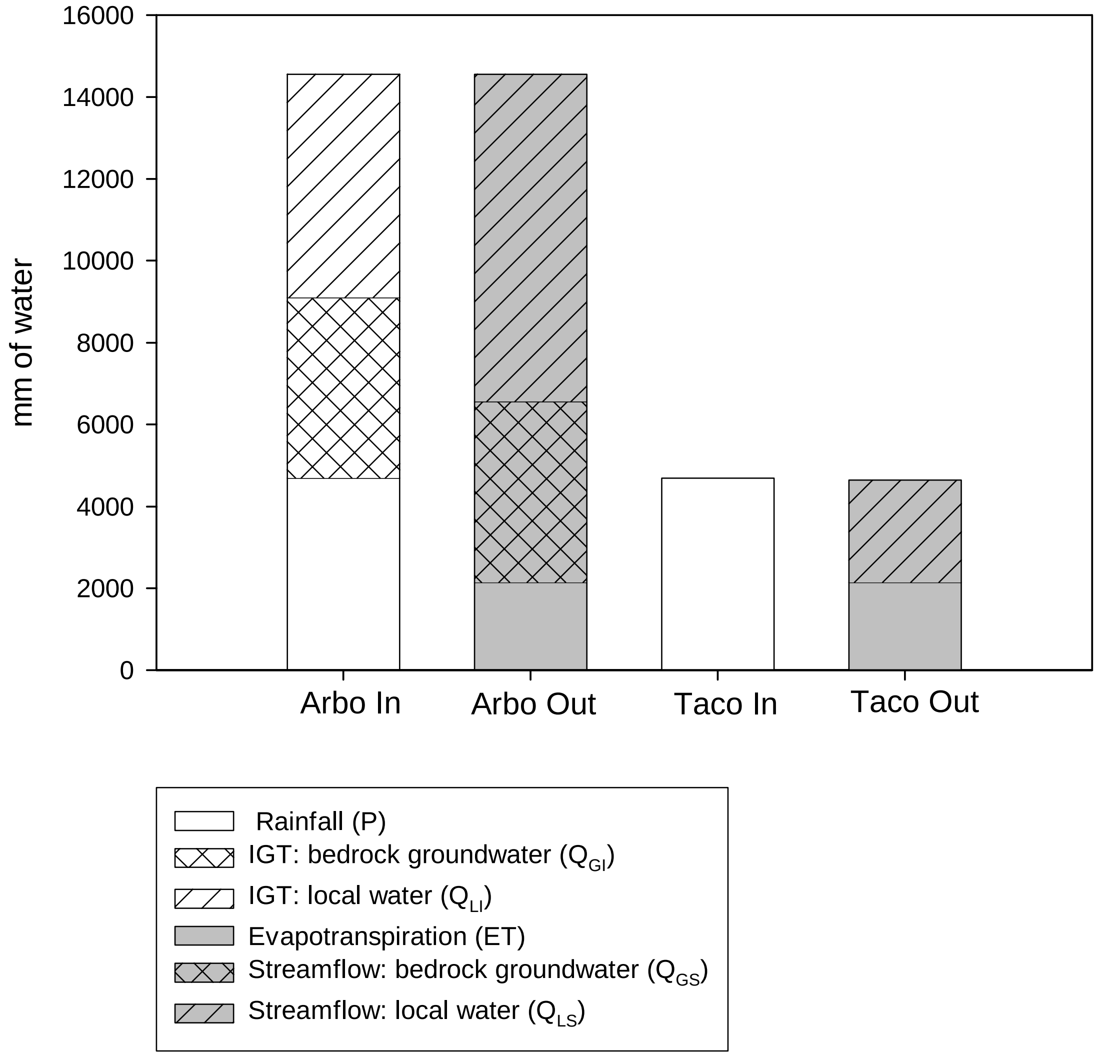


Figure 13. Annual water budget for the Taconazo and Arboleda watersheds for 12/99 to 11/00.

The inputs to the Arboleda and Taconazo watersheds are labeled Arbo In and Taco In, respectively. The outputs from the Arboleda and Taconazo watersheds are labeled Arbo Out and Taco Out, respectively. The inputs and outputs were normalized by the area of each watershed to allow for direct comparison.

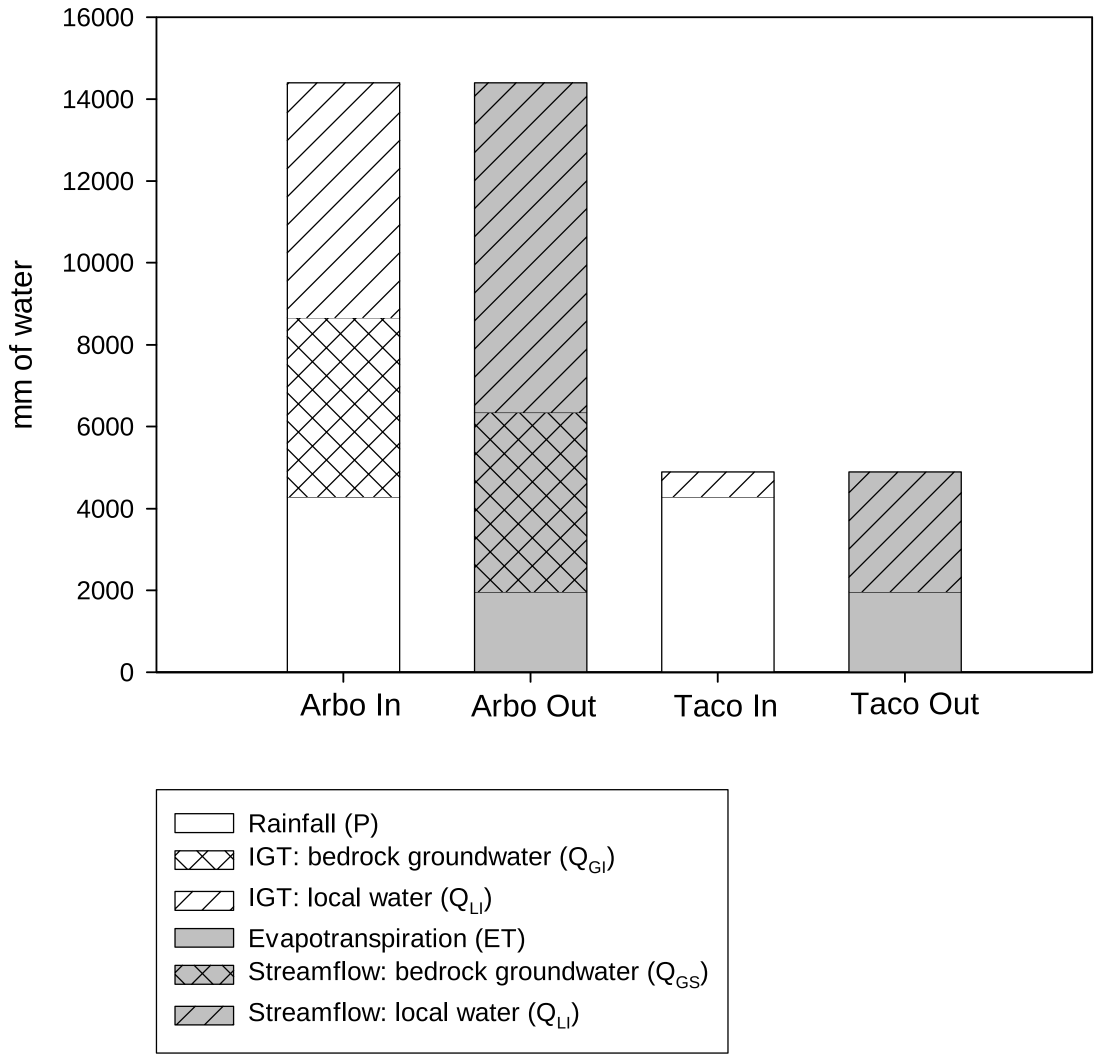


Figure 14. Annual water budget for the Taconazo and Arboleda watersheds for 12/00 to 11/01.

The inputs to the Arboleda and Taconazo watersheds are labeled Arbo In and Taco In, respectively. The outputs from the Arboleda and Taconazo watersheds are labeled Arbo Out and Taco Out, respectively. The inputs and outputs were normalized by the area of each watershed to allow for direct comparison.

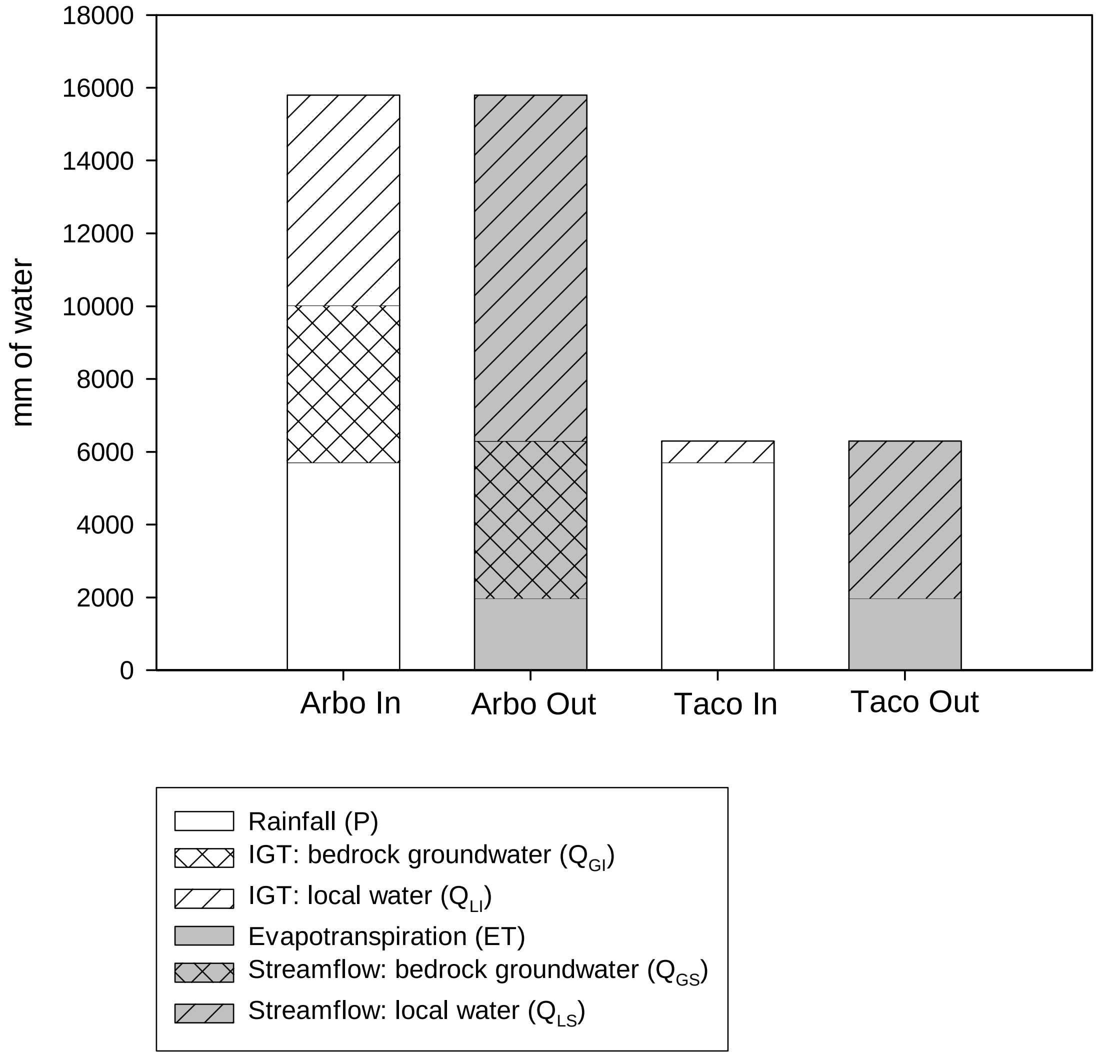


Figure 15. Annual water budget for the Taconazo and Arboleda watersheds for 12/01 to 11/02.

The inputs to the Arboleda and Taconazo watersheds are labeled Arbo In and Taco In, respectively. The outputs from the Arboleda and Taconazo watersheds are labeled Arbo Out and Taco Out, respectively. The inputs and outputs were normalized by the area of each watershed to allow for direct comparison.

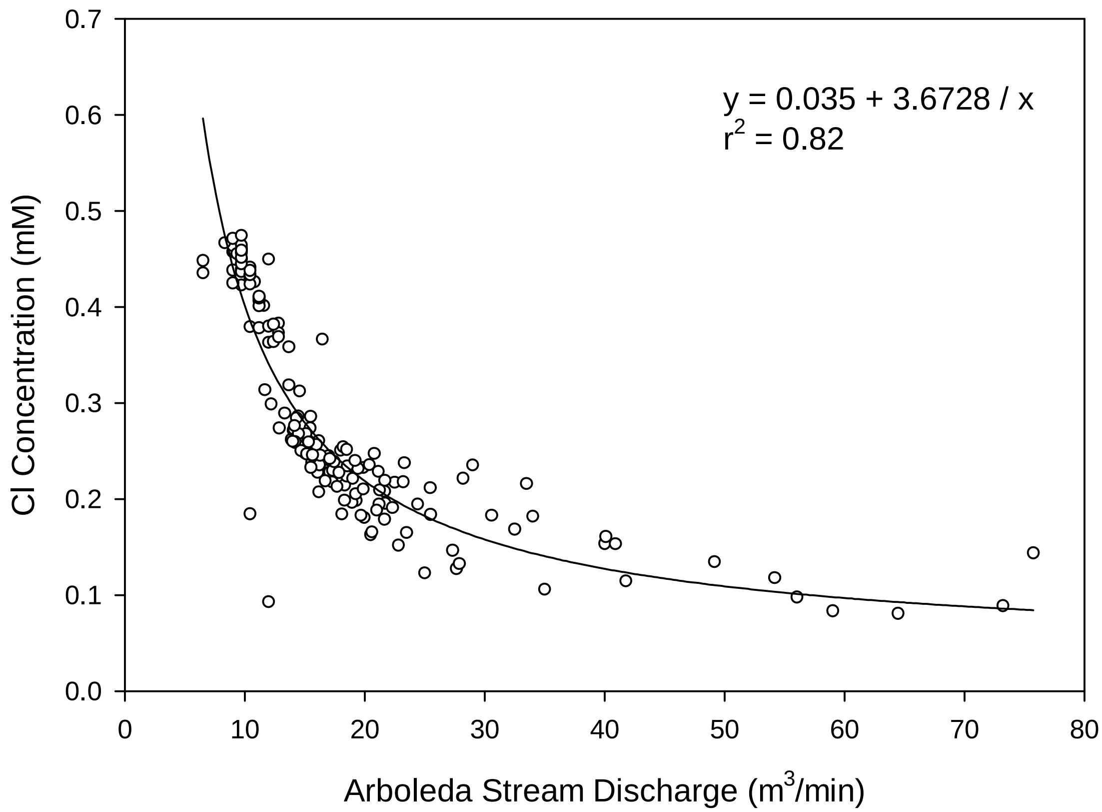


Figure 16. Chloride concentrations for samples collected at the Arboleda weir (between 3/00 and 2/01) plotted against stream discharge at the weir.

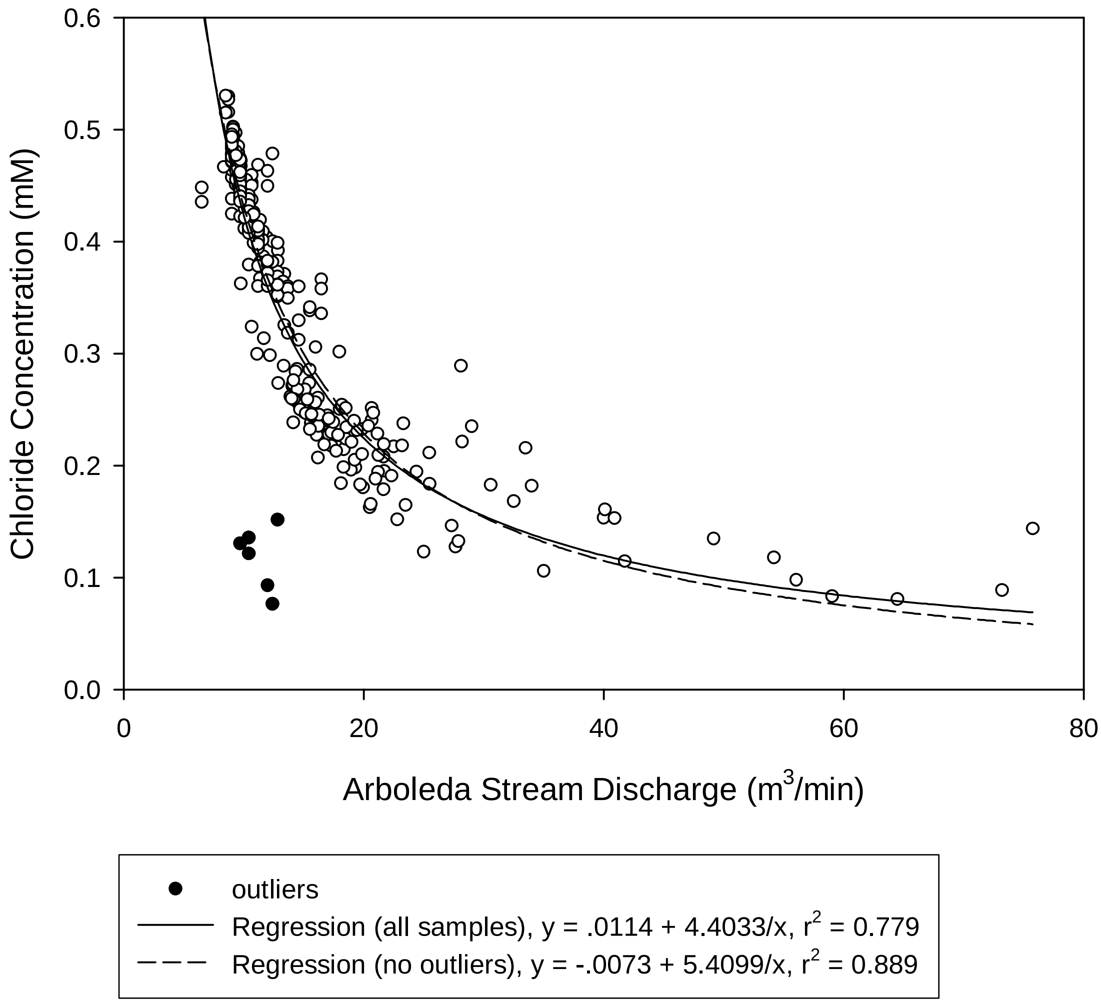


Figure 17. Chloride concentrations for samples collected at the Arboleda weir plotted against stream discharge.

Regressions were developed using all the samples, and using all the samples except the seven outliers (shown as solid circles). The regression based on all samples was used in the calculation of the Arboleda water budget.

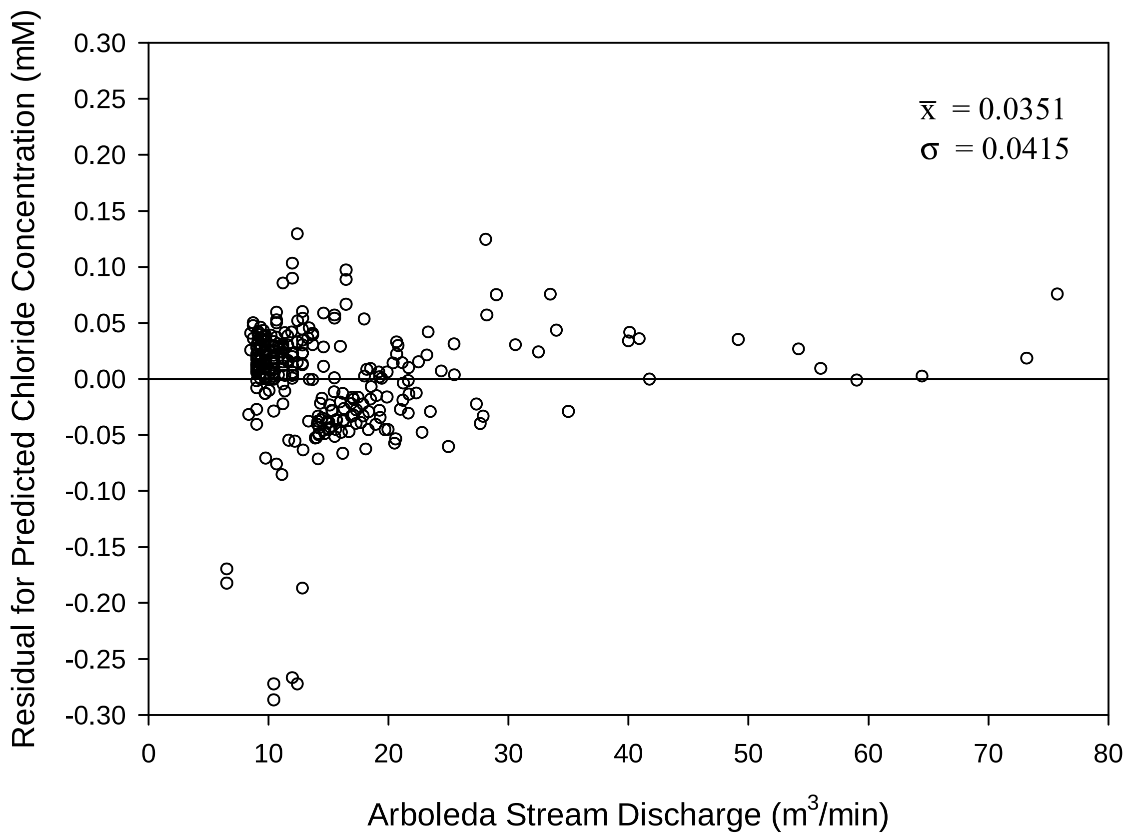
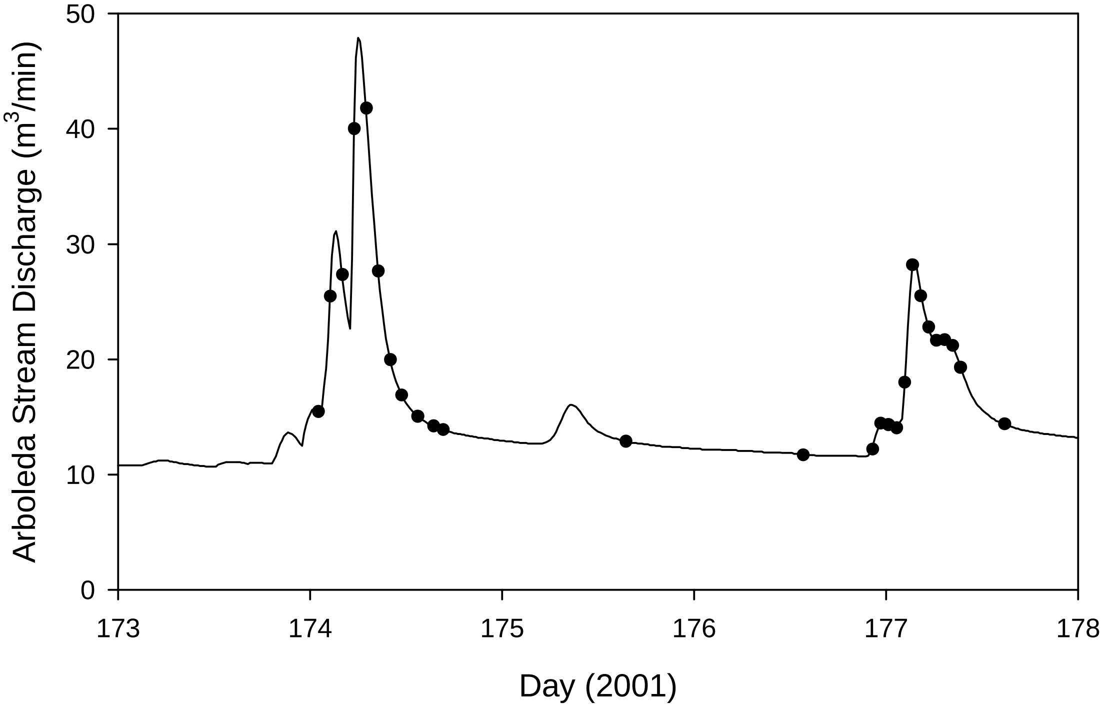


Figure 18. Plot of residuals for predicted chloride concentration (in mM) versus Arboleda stream discharge (in m^3/min) based on the regression that uses all the samples (Figure 12).



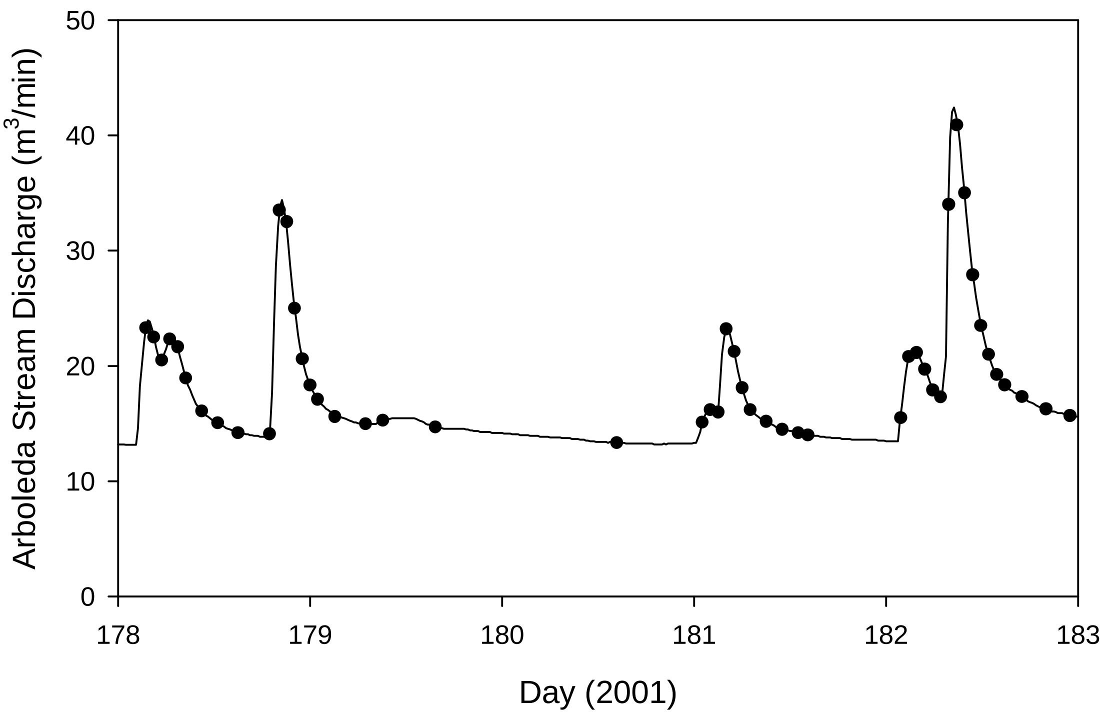
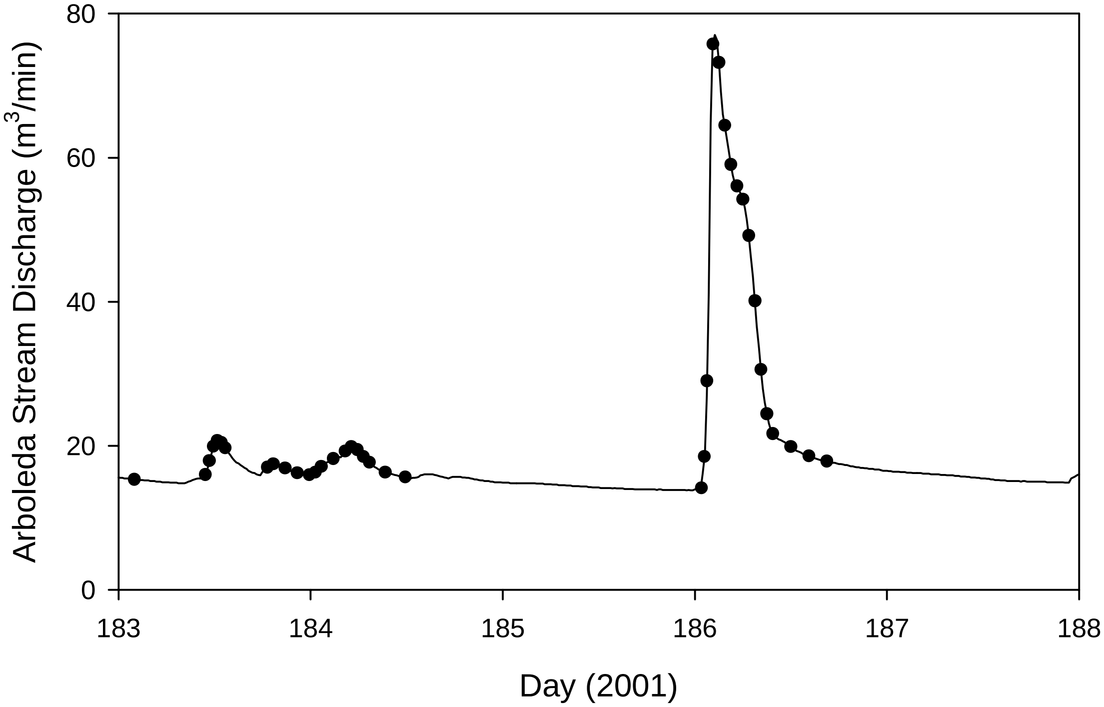
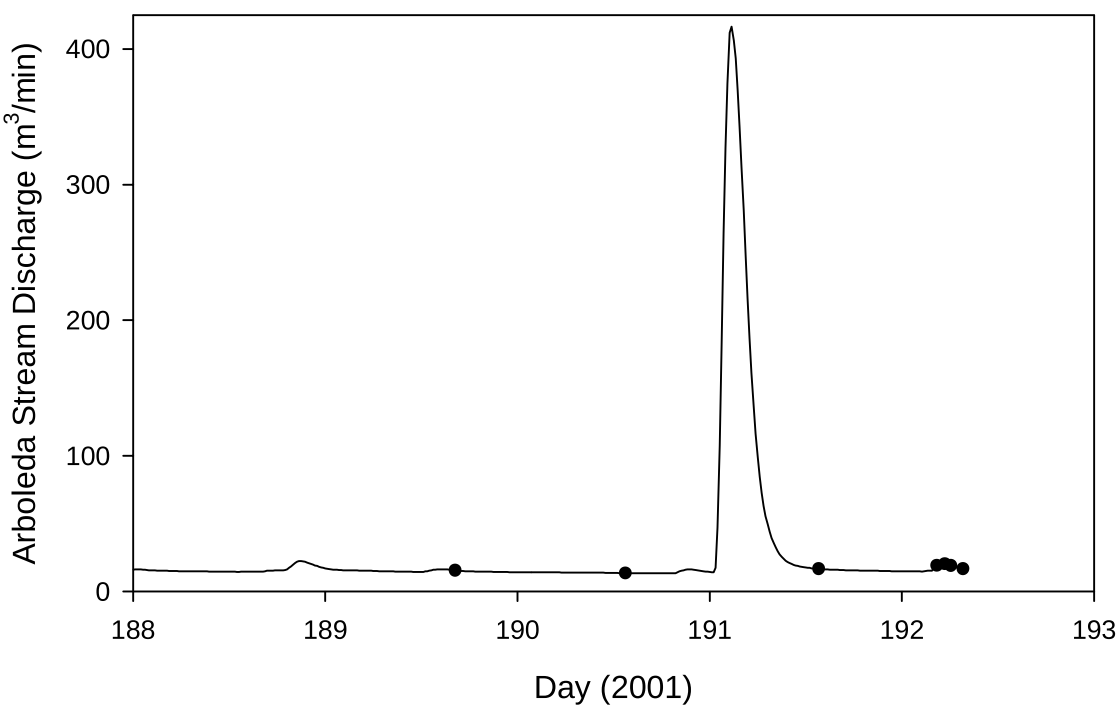


Figure 19. Storm samples collected at the Arboleda weir during June and July 2002.


80
60
40
20
0
183
184
185
186
187
188
Arboleda Stream Discharge (m3/min)
Day (2001)


400
300
200
100
0
188
189
190
191
192
193
Arboleda Stream Discharge (m3/min)
Day (2001)

Chapter 5: CHEMICAL BUDGETS

5.1. Chemical Budget Equations

Annual chemical budgets were calculated for the Arboleda and Taconazo watersheds for two years, 12/00-11/01 and 12/01-12/02, two of the years for which water budgets were also calculated. The compilation of chemical budgets was limited to the two years for which complete records of precipitation chemistry existed. Budgets were calculated for six major ions: Cl, SO_4, Na, K, Mg, and Ca.

The chemical budget for a tight watershed, one with no interbasin transfer, can be expressed as:

$$\Delta M = F_A - Q_S C_S - F_P \qquad (5\text{-}1)$$

where ΔM is the change in storage of the solute, F_A is the total flux of the solute from the atmosphere, $Q_S C_S$ is the dissolved stream export (product of stream discharge rate, Q_S, and streamwater concentration C_S), and F_P is the particulate stream export. ΔM represents the net storage effects of weathering, chemical precipitation, and uptake or release by the soil or vegetation. ΔM was not measured at the site and was calculated as a residual.

Based on the results of the water budget calculations, the Taconazo watershed is likely gaining local water due to interbasin groundwater transfer. The chemical budget expression needs to be modified to account for this additional flux:

$$\Delta M = F_A - Q_S C_S - F_P + Q_{LI} C_L \qquad (5\text{-}2)$$

where $Q_{LI} C_L$ represents the chemical input to the watershed by IGT of low-solute local water. For the Arboleda, which receives interbasin groundwater transfer of both bedrock groundwater and local water, the modified chemical budget equation is:

$$\Delta M = F_A - Q_S C_S - F_P + Q_{LI} C_L + Q_{GI} C_G \quad (5\text{-}3)$$

where $Q_{GI}C_G$ represents the chemical input to the watershed by IGT of high-solute bedrock groundwater. The dissolved stream export, $Q_S C_S$, was broken down into the two end-member waters that compose it:

$$\Delta M = F_A - (Q_{GS} C_G) - (Q_{LS} C_L) - F_P + Q_{LI} C_L + Q_{GI} C_G \quad (5\text{-}4)$$

5.2. Atmospheric Input

Bulk rainfall samples were collected for chemical analysis on a 10-meter tower located in a clearing with grasses and low shrubs, an "ideal" setting according to Galloway and Likens (1978, p. 79) (Figure 7). Samples were collected beginning in March 2000 through the end of the study in November 2002. The collection system was modeled after that at Hubbard Brook Experimental Forest (Likens and Bormann 1995) and consists of looped tubing that connects a collection funnel (15 cm in diameter) to a 4-liter plastic bottle. In the event that weekly precipitation exceeded about 220 mm (a rain depth that would fill a 4-liter bottle with a collection funnel 15 cm in diameter), precipitation beyond 220 cm entered an overflow bottle attached by flexible tubing to the main collection bottle. Weighing both the collection bottle and the overflow bottle at the end of each week allowed determination of the amount of precipitation at the collector (though, as recommended by Galloway and Likens (1978) tipping bucket precipitation data were used instead of the masses of rainfall measured at the collector in calculating atmospheric inputs of chemicals to the watershed; see below). Precipitation in the bottle was collected on a weekly basis.

At the end of each week (usually midmorning on Thursday or Friday) the complete apparatus (funnel, collection bottle, overflow bottle, and tubing) was removed from the field and replaced with a clean, new collector. Prior to removal, 50 mL of deionized water were poured through the funnel and into the collection bottle being removed, to rinse rainfall solutes from the funnel and tubing into the bottle. The removed collector was taken to the lab for weighing and sampling. The new collector was deployed with about 10 mL of deionized water in the looped tubing between the funnel and collection bottle in an effort to minimize the entry of insects into the collection bottle (this water prevented insects from simply walking from the funnel through the tubing into the collection bottle). Samples of deionized water were collected bi-weekly and analyzed for the six ions of interest (Cl, SO_4, Na, K, Mg, and Ca) along with all other water samples, to allow for correction of precipitation chemistry for the approximately 60 mL of deionized water added to each precipitation sample (in effect this was a small dilution of the precipitation sample, given the extremely low and often undetectable ion concentrations in the deionized water).

Back at the La Selva lab, water from the precipitation collection bottle was used to rinse a clean 50-mL plastic syringe, and then to fill the syringe. Several milliliters of precipitation was pushed through a disposable 0.45-micron membrane filter and discarded, to rinse the filter. Several more mL of precipitation were then pushed through the filter and used to rinse a new 20 mL plastic liquid scintillation vial and cap (the vial and cap were rinsed 3 times). Finally, the vial was filled and sealed to collect the sample. Replicate samples were taken for both cation and anion analysis (4 vials in all) if the volume of precipitation was adequate.

Reagent-grade nitric acid was used to preserve cation samples. The cation and anion samples were refrigerated until chemical analysis using ion chromatography at Florida

International University (Dionex DX 100) for samples collected from 12/98 to 02/00 or North Carolina State University (Dionex DX 500) for samples collected from 02/00 to 11/02.

The atmospheric input for each solute was determined on a weekly basis by multiplying the amount of rainfall (in mm from OTS tipping bucket data) by the solute concentration (in mM) of the bulk rainfall sample and a units conversion (mm rainfall x mmol/L x 10-6 L/mm3 x 1010 mm2/ha x 10-3 mol/mmol = input mol/ha). The annual solute input (in mol/ha) was calculated as the sum of the weekly inputs (Table 7). The uncertainty of annual solute input was between 7 and 8 percent (Appendix 11).

5.3. Dissolved Stream Export

Stream water samples were collected at two locations on the Taconazo, an upstream location (Taco8) and at the watershed outlet next to the weir (Taco) (Figure 8). Stream water samples were also collected at an upstream location on the Arboleda (Arbo4) and a downstream location at the weir (Arbo) (Figure 8). The samples were collected on a weekly basis throughout the 4-year study period. In addition to the weekly samples, an effort at more frequent sampling was undertaken over a four week period in June and July 2002 to sample individual storm events. The purpose of the storm sampling was to examine the relationship between solute concentration and stream discharge. Storm samples were collected using two ISCO 3700 automated water samplers (one at each weir), either initiated by a water level indicator or turned on manually, and manually shut off after the completion of the storm. For streamwater samples collected directly from the stream or from an ISCO bottle, the sample collection procedure was identical to that described earlier for collection of precipitation samples from the rainfall collection bottle. Stream water samples were filtered to 0.45 µm. Anion and cation samples were placed in separate vials with the cation samples being preserved with reagent grade nitric acid. Samples were refrigerated until analysis for major cations and anions using ion chromatography.

The annual dissolved stream export of each solute in the Arboleda watershed was calculated as the product of the annual water flux (Q_{GS} or Q_{LS}) and the respective end-member concentration (C_G or C_L). This method is similar to one used by Sickman et al. (2001) and Melack et al. (1998) where annual export was estimated as the product of an annual flux and a concentration, and allows the solute exportation from the two end members to be quantified separately.

For the Taconazo, two different approaches were considered for calculating dissolved stream export. One method, referred to as the regression method, used a regression based on the relationship between solute concentration and stream discharge. A solute concentration is predicted for stream water at the weir for each 15-minute interval, based on a concentration-discharge relationship and the 15-minute discharge data at the weir, and is multiplied by the volume of stream discharge during the 15-minute interval. The 15-minute products are summed for each budget year to give the total export of each solute. The second approach, referred to as the weekly method, calculated dissolved solute export as the product of the weekly stream sample concentration and the volume of stream discharge that occurred for approximately 3.5 days before and after the sample collection. The weekly products could then be summed for each budget year.

The weekly approach was used by itself to calculate dissolved stream export in several studies (Likens and Bormann 1995; Johnson and van Hook 1989) and the weekly approach was also used in combination with regressions that accounted for storms in additional studies (Lesack and Melack 1996; Lesack 1993b; Bruijnzeel 1983) (Table 8). The weekly method is appropriate to use in situations when a strong relationship between solute concentration and stream discharge does not exist. In cases when there is a connection between concentration and discharge, the weekly method tends to over estimate solute export because most weekly samples are collected under baseflow conditions, which typically have higher concentrations. Several solutes, including SO_4, Na, K, and Ca, do not exhibit a strong concentration-discharge relationship (Figures 20-23), indicating non-hydrologic controls may affect the solute export and the weekly method may be better suited to these solutes.

Biologic controls have been shown to influence solutes, especially K and Ca. Borman et al. (1969) noted that biologic activity tends to reduce the concentration of nitrate and potassium during the summer. Though temporal variability was not evident in the solute export of SO_4, Na, K, and Ca on seasonal or monthly time scales, probably due to the relatively steady climatic conditions, it is likely that biologic activity still affects dissolved export. An increase in the woody biomass has the potential to decrease available calcium (Johnson and Van Hook 1995, p. 270 and 281). Likens and Bormann (1995, p. 108) found that significant amounts (greater than 40 percent) of potassium and calcium input by atmospheric sources can be stored annually in living and dead biomass whereas only minor amounts of sodium (2 percent) and sulfur (10 percent) are stored with nearly all the remaining amounts lost as dissolved export. In addition to biologic controls, the concentration of dissolved sulfur export was likely influenced by the occurrence of reducing conditions (see Section 5.6).

In instances when there was a stronger relationship between solute concentration and stream discharge (Figures 24 and 25), the regression method was more appropriate than the weekly method. The regression approach was used in many previous studies to predict dissolved solute concentration based on stream discharge (Salmon et al. 2001; Stoorvogel 1997; Malmer 1996) (Table 8). By using the regression method in instances when a good correlation exists between concentration and discharge, the solute export is less likely to be overestimated.

It is clear that the weekly method is best suited for situations when a relationship between concentration and stream discharge does not exist and the regression method is ideal when there is a clear relationship. However, it is difficult to determine exactly how strong the relationship between concentration and discharge must be before using the regression method over the weekly method. There is not an accepted quantitative basis for finding that cut-off point to use the weekly method rather than the regression approach.

Professor David Dickey (pers. comm. 7/03), with the North Carolina State University Statistics Department, suggested a quantitative way of determining the best method by comparing the solute export determined using each method with the "true export". The true export could be calculated by intensively measuring the solute concentration and stream discharge on a small time interval (for example, collect samples and discharge measurements hourly for one year). To date, no published studies have collected samples and discharge measurements intensively enough to make a comparison between estimated export using the weekly or regression methods and true export.

An attempt was made to quantitatively determine the best method to calculate export by comparing with the true export. The true export of each major ion from the Taconazo watershed was calculated for an 8.5-day period using measurements collected during the intensive storm sampling in June and July 2002 (Figure 26; Table 13). For the same time period, solute export was estimated using the weekly and regression methods (Table 13). Export calculations based on the weekly method were carried out using chemical concentrations for three different samples (one at baseflow, one at slightly elevated flow, and one at the peak of small storm), in an attempt to determine how sensitive the estimated solute export is to sample selection. The three samples were collected within approximately 8 hours of one another.

The results of the comparison did not match the expectation of the weekly model overestimating solute export of SO_4, K, and Mg when a baseflow sample was used for the calculation. Additionally, the solute export estimated using the weekly method was very sensitive to the stream discharge at the time of sample collection (Table 13). The sensitivity to the discharge at the time of sample collection was so strong that an accurate comparison of the weekly and regression methods is probably not meaningful for a single 8.5-day period. The comparison test is sound in theory, but it requires a data set of much longer than 8.5 days.

Due to the fact that a conclusive application of the comparison test described above would require a longer period of closely-spaced chemical measurements, a criterion was needed to identify the best calculation method for dissolved solute export. Rather than use the same method for each solute, an approach similar to McDowell and Asbury (1994) was used. In instances when the stream discharge was able to explain a significant amount of variance in the stream water concentration for a solute, the regression method was used to compute export. When stream discharge did not display a strong relationship with the concentration of a solute, the weekly approach was used. Similarly, each solute in this study was individually examined to determine the best calculation method. The decision to use the weekly method rather than the regression method for particular solutes was somewhat subjective because no clear, rigorous quantitative test is available for this decision. As in the work by McDowell and Asbury (1994), we used our judgment in deciding for which solutes the weekly method or the regression method would be used. For example, concentrations of Cl and Mg in stream samples clearly indicate a relatively strong relationship (r^2 about 0.4 or greater) with stream discharge (Figures 24 and 25) while SO_4, Na, K, and Ca did not display a clear relationship (r^2 values from .03 to .26). Thus, it was decided to use the regression method for Cl and Mg and the weekly method for SO_4, Na, K, and Ca. It is not surprising that the weekly method was the best choice for solutes where controls other than stream discharge are known to exist. For K and Ca, dissolved solute export is affected by uptake and release by vegetation, and SO_4 can be influenced if conditions are favorable for reduction.

The annual dissolved solute export for each ion was calculated for both budget years in mol/ha (Table 7). A discussion of the results is presented in Section 5.6 and the uncertainty calculation for dissolved export is presented in Appendix 11.

5.4. Particulate Export

The export of ions adsorbed to mineral particles and organic matter in the Arboleda and Taconazo streams represents a loss from each watershed. This loss is represented in equation (5-1) as F_P. Little research has been conducted to document the possible significance of adsorbed major ion loss due to particle export. Campo et al. (2000) conducted a study in a Mexican tropical dry forest (mean annual rainfall = 679mm, far less than La Selva) that looked at Ca^{2+}, K^+, and Mg^{2+} sorbed to organic matter and sediments. Campo et al. (2000) found significant variations in major ion export via particles depending on rainfall conditions. In a wet year (960 mm of precipitation), sorbed ions represented 0.5 percent, 0.1 percent, and 1.6 percent of total ion export for Mg^{2+}, K^+, and Ca^{2+}, respectively, as compared to 40.20 percent, 3.2 percent, and 28.6 percent of total Mg^{2+}, K^+, and Ca^{2+}, respectively, export in a dry year (435 mm of precipitation).

Studies examined the importance of the export of both the particle itself as well as any sorbed cations in the Eastern Pyrenees (Llorens et al. 1995), a tropical wet forest in the Ivory Coast (Stoorvogel et al. 1997), and a forested watershed in New Hampshire, USA (Likens and Bormann 1995; Bormann et al. 1974). These studies typically filtered suspended stream sediments and analyzed the entire particle plus any sorbed ions using x-ray fluorescence (XRF) (Stoorvogel et al. 1997; Llorens et al. 1995). Results for each study varied slightly depending on the ion, but generally the export of suspended particles constituted approximately 17 percent (Likens and Bormann 1995) to 19 percent (Llorens et al. 1995) of the total ion export. The values ranged from a low of 2 percent for Ca^{2+} (Likens and Bormann 1995) to a high of 50 percent for K^+ (Stoorvogel et al. 1997) (the latter from a watershed with abundant potassium feldspar in the bedrock).

Given that none of these sites have similar bedrock to the study watersheds and in some cases they have significantly different climate, vegetation, watershed size, and soils, it is difficult to draw direct comparisons with the Arboleda and Taconazo watersheds. Additionally, previous studies mainly focused on the export of particles plus sorbed ions. While the export of solid particles is relevant in some processes (e.g., the long-term landscape evolution) it is not directly relevant to the shorter-term (e.g., annual) biogeochemical cycling in the watershed, as ions bound in the crystal structures of mineral particles and not yet released to the hydrosphere through weathering and dissolution are not available to and involved in the same biogeochemical processes as dissolved and sorbed ions. For this reason, in estimation of annual budgets of actively-cycling ions, the export of ions sorbed onto particles is more relevant than the export of ions in the interior of particles themselves. It can be concluded that export of ions both within and sorbed onto particles constitutes approximately 17 to 19 percent of all ion export. Furthermore, it is safe to conclude the large majority of particle-based ion export is comprised of the particles and not the sorbed ions. Thus, it seems likely that the export of sorbed ions represents a very minor portion of the total ion export from the watersheds, almost certainly well within the calculated uncertainty in dissolved export (Table 7). For the purpose of the chemical budget calculations, it was taken to be zero.

The main chemical results of the study (Section 5.6) are not sensitive to this assumption. Underestimating the annual major ion export from each watershed by a small increment (on the order of several mol/ha) due to particle-based export would not affect the comparison between the Arboleda and Taconazo (because the increment for each ion would likely be the same or very similar for both watersheds) and the conclusions drawn from that comparison (Section 5.6).

5.5 Interbasin Groundwater Transfer

The solute input due to IGT of local water and bedrock groundwater was calculated for both budget years. In the case of the Arboleda, solute input from the IGT of local water and bedrock groundwater was calculated whereas only local water IGT occurred and was quantified for the Taconazo watershed. The annual input of each solute due to IGT was calculated as the product of the annual IGT water flux from Chapter 4 (Q_{GI} and Q_{LI} for the Arboleda and Q_{LI} for the Taconazo) and the respective end-member solute concentration (C_G or C_L) (see Equations 5-2 and 5-4). The annual solute input for each ion was calculated for both budget years in mol/ha (Table 7).

5.6. Results

The chemical budget equations presented in Section 5.1 were used to calculate the annual chemical budgets for each solute for the Arboleda and Taconazo watersheds. The results of the chemical budgets for each solute and each watershed were summarized in annual tables (Table 7) and annual stacked bar charts (Figures 27-32).

The annual Taconazo budgets were computed using equation 5-2 and the solute flux calculations presented in Sections 5.2-5.5. Annual chemical budgets for the Arboleda watershed were computed using Equation 5-4 and the solute flux calculations presented in Sections 5.2-5.5. The results of this study were compared with similar chemical budget studies (Table 10).

The most noticeable outcome of the chemical budgets was the large solute flux into and out of the Arboleda watershed. The Arboleda watershed receives an average of 18 times more Cl, 11 times more SO_4, 36 times more Na, 54 times more K, 220 times more Mg, and 71 times more Ca input than the Taconazo watershed. Total solute input to the Arboleda watershed is dominated by bedrock groundwater, which accounts for an average input of 87 percent of Cl, 84 percent of SO_4, 93 percent of Na, 94 percent of K, 99 percent of Mg, and 97 percent of Ca, as compared with the Taconazo watershed where total solute input is controlled by rainfall accounting for on average of 85 percent of Cl, 91 percent of SO_4, 84 percent of Na, 73 percent of K, 77 percent of Mg, and 87 percent of Ca. The remaining small portion of solute input to the Taconazo watershed (i.e., the portion not due to rainfall) is from the IGT of local water. The remaining portion of solute input to the Arboleda watershed (i.e., the portion not due to bedrock groundwater) is due to roughly equal amounts of rainfall and IGT of local water.

The increased solute export from the Arboleda is also primarily due to bedrock groundwater. The Arboleda watershed discharges an average of 23 times more Cl, 22 times more SO_4, 41 times more Na, 29 times more K, 116 times more Mg, and 80 times more Ca than the Taconazo watershed. Solute export from the Arboleda watershed is dominated by bedrock groundwater, which accounts for 88 percent of Cl, 88 percent of SO_4, 94 percent of Na, 93 percent of K, 98 percent of Mg, and 97 percent of Ca, with the remaining portion of solute export being comprised of local water. In comparison, all solute export from the Taconazo watershed is local water.

It is concluded that the extreme difference in the chemical budgets for the two watersheds is mainly due to IGT of bedrock groundwater (and local water as well to a lesser extent) into the Arboleda watershed. The large rates of solute discharge into and export out of the Arboleda watershed have not been observed in published small watershed budget studies (see Chapter 6). It is likely that underlying hydrological heterogeneities are influencing the path of water discharging from the regional groundwater flow system. The Arboleda watershed obviously has a much better connection with regional flow system. While specific evidence is not available to evaluate how and/or why the Arboleda is better connected to the regional groundwater system than the Taconazo, several possibilities exist including variation in the local volcanic stratigraphy or a connection through faults or dikes. Mixing at the boundary between local and regional groundwater systems may play a role in the large IGT of local water to the Arboleda watershed.

With IGT of bedrock groundwater accounting for such a large percentage of the Arboleda chemical budget, it is not possible to discern the smaller scale phenomena discussed below for the Taconazo watershed, such as export of solutes from weathering of bedrock, release or uptake of solutes due to the growth or decay of the forest ecosystem, excess chloride input to the watersheds via precipitation (in 12/00-11/01), and the reduction or adsorption of sulfate.

The Arboleda watershed was in steady state conditions (i.e. difference between inputs and outputs was within the range of uncertainty) for each solute during the 12/00-11/01 and 12/02-11/02 budget years. The same can be said of the Taconazo for some solutes and years: Na and Ca in both budget years, and Cl in the second budget year. Steady state conditions are expected for some solutes in primary or old secondary forests that have obtained a state of dynamic equilibrium if the site is underlain by extremely weathered soils (i.e., spodosols, oxisols) (Bruijnzeel 1991). Sites underlain by lower fertility soils (i.e. ultisols and oxisols) typically display lower solute losses (Bruijnzeel 1991). The results of the Taconazo chemical budgets are discussed below.

Taconazo chemical budget results for budget year 12/00-11/01 were very similar to budget year 12/01-11/02 for each solute with the exception of chloride. A significant excess of Cl input over export (+963 mol/ha) was found in for the 12/00-11/01 budget year whereas results for the following budget year indicated that chloride was at steady state. The gain in Cl for the first budget year was due to a large Cl input by precipitation (2,372 mol/ha for 12/00-11/01 compared with only 1,880 mol/ha for 12/01/-11/02).

Unlike for Cl, the inputs of other major anions (SO_4) and cations (Na, K, Mg, and Ca) were not higher in the first budget year than in the second. The amount of rainfall that fell during the first budget year was average (4281 mm/year). To ensure there were no errors in the tipping bucket rain data set, the recorded volume of rainfall was compared with the volume recorded at the adjacent manual rain gauge (for 12/00-11/01, 4281 mm compared to 4611mm). Because duplicate rain samples are collected (if there is enough sample volume), it was possible to confirm that the high chloride concentrations in some rain samples were indeed accurate (Table 11). Though the Cl concentrations of the duplicate rain samples were always in close agreement, the samples were re-run anyway with no change in the results. The deionized water that dilutes the rainwater samples (Section 5.2) was also analyzed and ruled out as a possible source of excess chloride.

Anomalously high chloride precipitation inputs have been documented in other watersheds. Rain chemistry was analyzed over a ten-year period (1963-1974) at the Hubbard Brook experimental forest in New Hampshire, U.S.A (Likens and Bormann 1995). The long-term budgets found chloride to be nearly in balance, though large Cl inputs (313 mol/ha in 1970-71 and 322 mol/ha in 1972-73 as compared to the ten-year average of 175 mol/ha) recorded during two of the years were well in excess of Cl export by stream flow during these years. The larger than average Cl input was the result of three or four samples with high concentrations. The samples did not display any evidence of contamination and they were re-run to verify the original results. No definitive conclusions for the excess Cl input were reached (Likens and Bormann 1995, p. 78-79).

The majority of Cl as well as Na input to the Arboleda and Taconazo watersheds was found to originate from sea salt aerosols deposited as dissolved solutes in precipitation (Eklund et al. 1997). If the excess Cl input was due to weather related phenomena originating in the Caribbean Sea or Pacific Ocean, it would be expected that the input of Na would also increase. A corresponding increase in Na concentration was not observed, indicating that the excess Cl was not due to a large sea salt event (McDowell pers. comm. 07/03).

La Selva is located in relatively close vicinity to several active volcanoes including Volcan Poas and Volcan Arenal. Volcanic activity adjacent to a Columbian tropical forest was previously correlated with high sulfate concentrations and acidity in precipitation (Veneklaas 1990). Johnson and Parnell (1986) found a correlation between eruptions of volcanic gas from Volcan Masaya in Nicaragua and high concentrations of HCl and H_2SO_4 in precipitation. There is convincing evidence that the rainfall chemistry at La Selva is influenced by volcanic venting based on the percentage and high concentrations of non-sea-salt sulfate deposited at La Selva, the proximity of La Selva to several volcanoes, and the correlation among deposition of non-sea-salt Cl, non-sea-salt SO_4, and H^+ (Eklund et al. 1997). Volcan Poas has a history of frequent phreatic eruptions (i.e. volcanic eruption of steam caused by heating of groundwater by an underlying magma source) and fumarolic activity (i.e. escape of volcanic fumes from a vent or hole) resulting in the release of volcanic gases that have the potential to affect the precipitation chemistry at La Selva (Pringle et al. 1993). Elevated Cl and SO_4 concentrations were found for several weeks (12/22/00, 1/19/01, 2/02/01, 2/09/01, 2/16/01, 3/9/01, and 3/23/01) during budget year 12/00-11/01. No large magma eruptions were reported during this budget year, though gas columns from Volcan Poas reportedly reached 300-500 meters in height at times between July 2000 and May 2001 (Observatorio Vulcanologico y Sismologico de Costa Rica 2003). An extended period (35 hours) of seismic activity was recorded during March 1-3, 2001 (Observatorio Vulcanologico y Sismologico de Costa Rica 2003), in association with the appearance of new fumaroles within the main crater and the surrounding pyroclastic cone. The precipitation sample collected at La Selva on March 9, 2001 had the highest Cl concentration (0.357 mmol/L) and the highest SO_4 concentration (0.0122 mmol/L) observed during the 12/00-11/01 budget year.

While atmospheric Cl input to the watersheds was high during early 2001, possibly due to nearby volcanic emissions, a corresponding increase in chloride output by stream flow was not observed. The weekly stream water samples collected during the weeks when increased Cl concentration in precipitation was observed did not display increased Cl concentrations. The precipitation samples were composite samples representing the rain chemistry that for the entire week whereas the stream water samples were weekly grab samples that represented stream water chemistry at the moment of collection. It is possible that the excess chloride was deposited at such a time during the week that it would not be detected in the stream water sample (e.g., in a storm between stream samples) and thus not reflected in the Cl export. Furthermore, the Cl export is predicted based on a relationship between Cl concentration and stream discharge. Anomalously high short-term atmospheric inputs of Cl, possibly in association with nearby volcanic activity, could have resulted in transient anomalously high streamwater Cl concentrations that were not captured in the stream sampling program. These conditions would represent deviations from the concentration-discharge relationship used to estimate Cl concentrations from 15-minute discharge data and thereby compute Cl export. This is one possible explanation for the excess of Cl input over stream export in this budget year (basically, that the extra atmospheric Cl input was measured because the atmospheric deposition collector was continuously open but the extra stream export of Cl that must have followed was missed by the stream sampling program).

Also, volcanic emissions as the source of excess Cl deposition is consistent with the observation that atmospheric deposition of the major cations (Na, K, Mg, and Ca) was not anomalously high when Cl was high; H would likely be the dominant cation for excess atmospheric Cl from a volcanic source (Cl would be emitted as HCl).

The Taconazo sulfate budget showed an excess of inputs over outputs: +88 mol/ha during the 12/00-11/01 budget year and +115 mol/ha during the 12/01-11/02 budget year. Slightly more sulfate was input to the watershed from 12/01 to 11/02 (221 mol/ha) than from 12/00 to 11/01 (147 mol/ha), though this is not unexpected due to the increased rainfall that occurred during the second budget year (5706mm in 12/01-11/02 compared with 4281mm in 12/00-11/01). The dissolved export of sulfate was also slightly greater during the second budget (122 mol/ha) than the first budget year (76 mol/ha). The difference between the input and output of sulfate for both chemical budget years was roughly equal to the amount lost as dissolved export.

There are two potential mechanisms that could contribute to the excess of sulfate inputs over export: sulfate reduction and sulfate adsorption. Reducing conditions were inferred to be present in both watersheds based on the regular absence of nitrate in groundwater wells 2, 5, 6, and 8, and the frequent absence at well 3 (Table 12). Occurrence of such reducing conditions appears to be localized and heterogeneous. Wells 4 and 5 are within several meters of each other, wells 1 and 2 face each other on opposite sides of the Arboleda stream, and wells 6 and 7 face each other across the Taconazo stream; in each of these three pairs of wells, one well almost always shows the presence of nitrate while the other shows an absence.

Because nitrate reduction is more thermodynamically favorable than sulfate reduction (Richardson and Vepraskas, p. 87-90), it stands to reason that sulfate reduction may have occurred in groundwater lacking nitrate. A comparison of nitrate and sulfate data was conducted for one year (Table 12) to determine if a correlation between a lack of nitrate and a lack of sulfate existed. An absence of nitrate was found to correlate with an absence of sulfate at well 5 and the presence of nitrate was found to correlate with the presence of sulfate at wells 1, 3, and well 7, which supports the idea of sulfate being reduced. The data were not entirely supportive of sulfate reduction at other locations including well 4 where sulfate was absent but nitrate was present, and at wells 2, 6, and 8 where nitrate was absent, but sulfate was present. As a whole, the data are not conclusive on this topic, but are consistent with the possibility of sulfate reduction in some places (e.g., near well 5). Any reduced sulfate in the watershed could not be measured as sulfate export, though most of the reduced sulfur would probably leave the watershed in stream flow or through volatilization to the atmosphere.

Sulfate in the watershed may also be retained through sorption to soils. Johnson et al. (1979) found that tropical soils have a high capacity to permanently retain sulfate. This was found to hold true in a plot-scale study at La Selva likely due to the high amounts of free iron and aluminum oxides in the soil (Johnson et al. 1979). Johnson et al. (1979) measured an annual sulfate input of 130 mol/ha compared to our inputs of 147 mol/ha and 221 mol/ha in 12/00-11/01 and 12/01-11/02, respectively. An annual gain of approximately 122 mol/ha was calculated by Johnson et al. as difference between precipitation inputs and soil leaching at a depth of 60 cm below ground surface, measured using tension lysimeters. These results compare well with the results of the current study, which report sulfate retention of 88 mol/ha in 12/00-11/01 and 115 mol/ha in 12/01-11/02. It is likely that the majority of the difference between sulfate inputs and sulfate outputs from the Taconazo watershed is attributable to sorption rather than reduction.

The chemical budgets for both years indicate that the Taconazo watershed is in steady state conditions with respect to Na and Ca. The Taconazo watershed experienced a net loss of K during the 12/00-11/01 budget year (-165 mol/ha) and during the 12/01-11/02 budget year (-162 mol/ha). This net loss of K from the watershed may be due to a net release of K stored in living and dead biomass Likens and Bormann (1995 p. 108). The Taconazo watershed also experienced a net loss of Mg during the 12/00-11/01 budget year (-256 mol/ha) and the 12/01-11/02 budget year (-330 mol/ha). The net loss of Mg from the watershed may be due to weathering of Mg-rich rock in the Taconazo stream and lithic fragments in the soil (Sollins et al. 1994, p. 39) and is supported by Bruijnzeel's (1983) conclusion that lithology is the dominant factor in determining net solute losses in undisturbed basins. Several other studies found watersheds experiencing a net loss of base cations including Mg and K (Table 10).

Table 7. Annual chemical budget results the Arboleda and Taconazo watersheds.

All values are in mol/ha. Change = inputs – outputs.

Taconazo Watershed 12/00-11/01

Inputs	Cl	SO$_4$	Na	K	Mg	Ca
Rain	2,372 ± 37	147 ± 2	1,797 ± 33	98 ± 2	229 ± 4	445 ± 7
Q_{GI}	0	0	0	0	0	0
Q_{LI}	387 ± 309	17 ± 19	400 ± 334	55 ± 64	76 ± 66	74 ± 83
Total	2,759 ± 311	164 ± 19	2,197 ± 335	153 ± 64	305 ± 66	519 ± 84

Outputs	Cl	SO$_4$	Na	K	Mg	Ca
ET	0	0	0	0	0	0
Q_{GS}	0	0	0	0	0	0
Q_{LS}	1,796 ± 7	76 ± 1	1,893 ± 24	319 ± 5	560 ± 1	451 ± 8
Total	1,796 ± 7	76 ± 1	1,893 ± 24	319 ± 5	560 ± 1	451 ± 8
Change	963 ± 311	88 ± 19	304 ± 336	-165 ± 64	-256 ± 66	69 ± 84

Taconazo Watershed 12/01-11/02

Inputs	Cl	SO$_4$	Na	K	Mg	Ca
Rain	1,880 ± 31	221 ± 4	2,347 ± 39	244 ± 5	272 ± 4	511 ± 9
Q_{GI}	0	0	0	0	0	0
Q_{LI}	373 ± 354	16 ± 20	385 ± 378	53 ± 68	73 ± 74	72 ± 88
Total	2,253 ± 356	237 ± 20	2,732 ± 380	297 ± 68	345 ± 74	583 ± 89

Outputs	Cl	SO$_4$	Na	K	Mg	Ca
ET	0	0	0	0	0	0
Q_{GS}	0	0	0	0	0	0
Q_{LS}	2,209 ± 11	122 ± 2	2,559 ± 28	459 ± 6	675 ± 2	526 ± 7
Total	2,209 ± 11	122 ± 2	2,559 ± 28	459 ± 6	675 ± 2	526 ± 7
Change	44 ± 356	115 ± 20	173 ± 381	-162 ± 68	-330 ± 74	56 ± 89

Arboleda Watershed 12/00-11/01

Inputs	Cl	SO_4	Na	K	Mg	Ca
Rain	2,372 ± 37	147 ± 2	1,797 ± 33	98 ± 2	229 ± 4	445 ± 7
Q_{GI}	39,873 ± 1,629	1,825 ± 104	83,662 ± 4,977	10,374 ± 668	70,655 ± 4,700	38,027 ± 2,406
Q_{LI}	3,543 ± 895	154 ± 126	3,664 ± 1,295	505 ± 457	691 ± 308	682 ± 576
Total	45,787 ± 1,859	2,126 ± 164	89,124 ± 5,143	10,977 ± 809	71,575 ± 4,710	39,154 ± 2,475

Outputs	Cl	SO_4	Na	K	Mg	Ca
ET	0	0	0	0	0	0
Q_{GS}	39,873 ± 1,629	1,825 ± 104	83,662 ± 4,977	10,374 ± 668	70,655 ± 4,700	38,027 ± 2,406
Q_{LS}	5,104 ± 1,117	221 ± 176	5,279 ± 1,719	728 ± 636	996 ± 418	982 ± 802
Total	44,977 ± 1,976	2,046 ± 204	88,941 ± 5,265	11,102 ± 923	71,651 ± 4,718	39,009 ± 2,537
Change	810 ± 2,713	79 ± 262	183 ± 7,360	-125 ± 1,227	-76 ± 6,667	145 ± 3,544

Arboleda Watershed 12/01-11/02

Inputs	Cl	SO_4	Na	K	Mg	Ca
Rain	1,880 ± 31	221 ± 4	2,347 ± 39	244 ± 5	272 ± 4	511 ± 9
Q_{GI}	39,281 ± 1,699	1,798 ± 106	82,421 ± 5,041	10,220 ± 674	69,607 ± 4,735	37,463 ± 2,430
Q_{LI}	3,637 ± 938	158 ± 128	3,761 ± 1,332	519 ± 461	710 ± 314	700 ± 582
Total	44,798 ± 1,941	2,176 ± 166	88,529 ± 5,214	10,983 ± 817	70,588 ± 4,745	38,673 ± 2,499

Outputs	Cl	SO_4	Na	K	Mg	Ca
ET	0	0	0	0	0	0
Q_{GS}	39,281 ± 1,699	1,798 ± 106	82,421 ± 5,041	10,220 ± 674	69,607 ± 4,735	37,463 ± 2,430
Q_{LS}	6,017 ± 1,307	261 ± 207	6,222 ± 2,020	858 ± 749	1,174 ± 491	1,158 ± 945
Total	45,298 ± 2,144	2,059 ± 232	88,644 ± 5,430	11,078 ± 1,008	70,781 ± 4,760	38,620 ± 2,607
Change	-500 ± 2,892	118 ± 286	-114 ± 7,528	-96 ± 1,298	-192 ± 6,721	53 ± 3,611

Table 8. Summary of methods previously used to calculate annual dissolved export

Article	Location	Area (ha)	Vegetation	Rainfall (mm/yr)	Solute(s)[1]	Annual Export Calculation Method
Sickman et al. 2001	Sierra Nevada, California, U.S.	7 basins; 25 to 441	~25 percent vegetated	1510	N	product of annual Q and VWM C
Melack et al. 1998	Sierra Nevada, California, U.S.	8 basins; 25 to 441	~25 percent vegetated	1510	Cl, SO_4, NO_3, Na, K, Mg, Ca	product of annual Q and VWM C
Bruijnzeel 1983	Central Java, Indonesia	19	plantation forest	4770	Na, K, Mg, Ca	regressions of storm volume and load for stormflow; Q and C products for baseflow
Johnson and van Hook 1989	Walker Branch, Tennessee, U.S.	97.5	forest; oak and hickory	1390	Na, K, Mg, Ca	products of weekly Q and C summed for the budget year
Likens and Bormann 1995	New Hampshire, U.S.	6 basins, 12 to 43	northern hardwood	1295	Cl, SO_4, Na, K, Mg, Ca	products of weekly Q and C summed for the budget year
Stoorvogel et al. 1997	Ivory Coast	117	tropical forest	1833	K, Mg, Ca, P	regressions of Q and EC used to predict C
Malmer 1996	Malaysia	NA	tropical forest	3490	K, Mg, Ca, N, P	unclear; regressions to predict C were calculated
Salmon et al. 2001	Southwest Chile	1.2	temperate forest	5880	Cl, SO_4, Na, K, Mg, Ca	did not calculate solute export; developed regressions of Q and C
McDowell and Asbury 1994	Puerto Rico	3 basins; 16, 262, [illegible]	tropical forest	2500 to 5000+	Cl, SO_4, NO_3, Na, K, Mg, Ca	regressions of C vs. log Q used to predict C
Lesack 1993b and Lesack and Melack 1996	Amazon	23.4	tropical forest	2870	Cl, SO_4, NO_3, Na, K, Mg, Ca	regressions of Q and storm size for stormflow; summation of Q and C products for baseflow
McLean et al. 1999	Alaska, U.S.	2 basins; 520, 570	forest	285 to 500	SO_4, Na, K, Mg, Ca	products of daily Q and C (estimated as linear interpolation between weekly samples)
Williams et al. 1997 Williams and Melack 1997	Amazon	2 basins; 23.4, 18	tropical forest	2754	Cl, SO_4, NO_3, Na, K, Mg, Ca	unclear

VWM = volume weighted mean; C = stream concentration; EC = electroconductivity; Q = volumetric stream discharge

[1] not a comprehensive list of all solutes that were analyzed

Table 9. Results from studies of annual export of Mg, K, and Ca (dissolved and particulate)

Study:	**Bormann et al. (1974)**	**Stoorvogel et al. (1997)**	**Campo et al. (2000)**		**Llorens et al. (1995)**
Study Site:					
Location	New Hampshire, USA	Tai National Park, Ivory Coast	Chamela Biological Station, Mexico		Vallcebre, Eastern Pyrenees
Size	15.6-ha watershed	117-ha watershed	plots in 5 watersheds (12-28ha)		17-ha subcatchment
Elevation	229 to 1006m	NA	50m to 160m		1400m to 1700m
Rainfall	1300 mm/year	mean avg rainfall 1833mm	mean annual precip is 679 mm		mean annual precip is 850 mm
Geology	3.5-6 m till underlain by gneiss	granite and assoc. meta rocks	rhyolite to rhyodacite		clayey mudrock; limestone
Vegetation	mature hardwood forest	undisturbed humid evergreen forest	deciduous trees; species are leaf-less for several months each year		abandoned agriculture dense grasslands
Climate	humid continental	tropical wet; wet season Feb to Nov; no rain from Dec to Feb	tropical dry forest wet season from June to October		Mediterranean mountainous dry season from June to Aug
Annual Export Results:			Dry Year (435 mm rainfall)	Wet Year (960 mm rainfall)	Export of all ions including Mg, K, Ca
Magnesium					
dissolved Mg	93.2% (107.0 mol/ha)	83% (320.9 mol/ha)	71.4% (0.4 mol/ha)	99.5% (146.9 mol/ha	
Mg sorbed to O.M.			28.6% (0.2 mol/ha)	0.3% (0.5 mol/ha)	
Mg sorbed to sediment			0.0% (<.001 mol/ha)	0.2% (0.2 mol/ha)	79% of total export is as dissolved load
O.M. + sorbed Mg	1.8% (2.1 mol/ha)	0% (0.0 mol/ha)			
sediment + sorbed Mg	5.0% (5.8 mol/ha)	17% (65.8 mol/ha)			
TSS + sorbed Mg					20% of total export is TSS and ions sorbed to TSS
Potassium					
dissolved K	74.3% (38.0 mol/ha)	50% (237.8 mol/ha)	96.8% (1.5 mol/ha)	99.9% (123.3 mol/ha	
K sorbed to O.M.			3.2% (0.1 mol/ha)	0.1% (0.1 mol/ha)	
K sorbed to sediment			0.0% (<.001 mol/ha)	0.0% (0.1 mol/ha)	1% of total export is as bedload
O.M. + sorbed K	0.5% (0.3 mol/ha)	0% (0.0 mol/ha)			
sediment + sorbed K	25.2% (13.0 mol/ha)	50% (240.4 mol/ha)			
TSS + sorbed K					
Calcium					
Dissolved Ca	97.7% (242.0 mol/ha)	75% (476.6 mol/ha)	59.8% (1.7 mol/ha)	98.3% (236.5 mol/ha	
Ca sorbed to O.M.			38.5% (1.1 mol/ha)	1.2% (3.0 mol/ha)	
Ca sorbed to Sediment			1.7% (0.05 mol/ha)	0.4% (1.0 mol/ha)	
O.M. + sorbed Ca	1.7% (4.2 mol/ha)	0% (0.0 mol/ha)			
sediment + sorbed Ca	0.6% (1.5 mol/ha)	25% (154.7 mol/ha)			
TSS + sorbed Ca					

TSS: total suspended solids (sediment + organic matter); O.M.: organic matter

Table 10. Comparison of net annual solute change (in mol/ha) where net change is defined as watershed inputs minus dissolved outputs.

If the net change is within the degree of uncertainty, it is shown as zero

	Location	Cl	SO_4	Na	K	Mg	Ca
(1)	Taconazo 12/00-11/01	963	88	0	-165	-256	0
	Taconazo 12/00-11/02	0	115	0	-162	-330	0
(2)	Arboleda 12/00-11/01	0	0	0	0	0	0
	Arboleda 12/00-11/02	0	0	0	0	0	0
(3)	Hubbard Brook, N.H.	46	--	-245	-25	-105	-287
(4)	Tai National Park, Ivory Coast	--	--	--	-84	-267	-227
(5)	Puerto Rico	-56	21	0	138	53	125
(6)	Central Java, Indonesia	--	--	-613	-317	-1,090	-477
(7)	Central Amazon	-101	47	-51	7	11	26
(8)	Caura River, Venezuela	--	--	--	-348	-234	-354
(9)	Tai Lam Chung, Hong Kong	--	--	--	-281	21	-274
(10)	Bt. Berembun, Malaysia	--	--	--	-350	-354	-279

(1) This study
(2) This study
(3) Likens and Bormann (1995); based on a 10-year average; adapted from Table 10 p. 60 and Table 13 p. 79
(4) Stoorvogel et al. (1997); adapted from Table 5
(5) McDowell and Asbury (1994); based on a 3-year average; adapted from Table 5
(6) Bruijnzeel (1983)
(7) Lesack and Melack (1996): adapted from table 3
(8) Lewis (1986) and Lewis et al. (1987) summarized by Bruijnzeel (1991)
(9) Lam (1978) summarized by Bruijnzeel (1991)
(10) Alternate computation to account for deep leakage by Bruijnzeel (1991) based on data from Abdul Rahim and Zulkifli Yusop (1986), Zulkifli Yusop (1989), and Zulkifli Yusop et al. (1989)

Table 11. Chloride concentrations (in mM) of bulk rainfall samples, duplicate samples, and rainfall quantities for weekly sample periods (in mm).

Sample Collection Date	Sample Period Begin Day	Sample Period End Day	Rainfall During Period	Bulk Rain Sample Cl, mM	Re-Run Samples Cl, mM
12/01/00	335.0	340.0	77.9	0.0758	
12/08/00	341.0	347.0	49.0	0.0383	
12/15/00	348.0	354.0	67.0	0.0675	
12/22/00	355.0	361.0	94.1	0.1616	0.1631
12/29/00	362.0	2.5	142.2	0.0320	
01/05/01	3.5	9.0	73.6	0.0481	
01/12/01	10.0	16.0	8.1	0.0649	
01/19/01	17.0	22.5	38.1	0.2825	NA
01/25/01	23.5	29.5	127.8	0.0340	
02/02/01	30.5	37.0	24.6	0.1484	
02/09/01	38.0	44.0	35.4	0.1888	0.1902
02/16/01	45.0	51.0	47.0	0.2562	0.2579
02/23/01	52.0	58.0	0.0	0.0000	
03/02/01	59.0	65.0	0.0	0.0000	
03/09/01	66.0	72.0	20.2	0.3569	0.3569
03/16/01	73.0	79.0	3.4	0.0000	
03/23/01	80.0	86.0	60.6	0.1312	
03/30/01	87.0	93.0	24.9	0.0510	

NA- not available

Table 12. Presence of nitrate (identified with an X) and concentrations of sulfate (in mM) in the Arboleda and Taconazo wa

Date	Well 1		Well 2		Well 3		Well 4		Well 5		Well 6		Well 7		Well 8		Arbo4		Arbo		Taco8		Taco	
	NO_3	SO_4	NO_3	SO_4	NO_3	SO_4	NO_3	SO_4	NO_3	SO_4	NO_3	SO_4	NO_3	SO_4	NO_3	SO_4	NO_3	SO_4	NO_3	SO_4	NO_3	SO_4	NO_3	SO_4
12/07/00	X	0.014		0.014	X	0.005	X	0.002		0.002		0.004	X	0.003		0.003	X	0.003	X	0.014	X	0.002	X	0.002
12/14/00	X	0.014		0.014	X	0.005	X	0.002		0.002		0.004	X	0.004		0.004	X	0.003	X	0.014	X	0.002	X	0.003
12/21/00	X	0.015		0.013	X	0.005	X	0.002		0.002		0.003	X	0.003		0.003	X	0.003	X	0.015	X	0.002	X	0.002
12/28/00	X	0.014		0.013	X	0.005	X	0.002		0.002		0.004	X	0.003		0.003	X	0.003	X	0.014	X	0.002	X	0.003
01/04/01	X	0.011	X	0.012	X	0.005	X	0.002		0.002		0.003	X	0.003	X	0.004	X	0.003	X	0.013	X	0.003	X	0.003
01/11/01	X	0.014		0.014	X	0.005	X	0.002		0.002		0.003	X	0.003		0.004	X	0.002	X	0.014	X	0.002	X	0.002
01/18/01	X	0.015		0.013	X	0.005	X	0.002		0.002	X	0.004	X	0.003		0.003	X	0.002	X	0.015	X	0.002	X	0.003
01/25/01	X	0.013		0.013	X	0.005	X	**0**		**0**		0.003	X	0.003	X	0.004	X	0.003	X	0.012	X	0.003	X	0.003
02/01/01	X	0.015		0.015	X	0.004	X	**0**		0.002		0.003	X	0.003		0.003	X	0.002	X	0.015	X	0.002	X	0.002
02/08/01	X	0.015		0.015	X	0.004	X	**0**		**0**		0.003	X	0.003		0.003	X	0.004	X	0.015	X	0.002	X	0.002
02/15/01	X	0.015		0.015	X	0.005	X	**0**		**0**		0.003	X	0.003		0.003	X	0.002	X	0.015	X	0.002	X	0.002
03/01/01	X	0.003		**0**	X	**0**	X	0.005		0.016	X	0.010	X	0.003		0.003	X	0.002	X	0.016	X	0.002	X	0.002
03/15/01	X	0.015		0.015	X	0.005	X	**0**		**0**		0.003	X	0.003		0.002	X	0.002	X	0.016	X	0.002	X	0.003
03/29/01	X	0.016		0.015	X	0.005	X	**0**		**0**		0.003	X	0.003		0.004	X	0.002	X	0.017	X	0.003	X	0.003
04/12/01	X	0.016		0.016	X	0.005	X	0.002		**0**		0.003	X	0.003		0.004	X	0.003	X	0.016	X	0.003	X	0.003
04/26/01	X	0.015		0.014		0.005	X	0.002		0.002		0.004	X	0.003		0.004		0.002		0.016	X	0.002	X	0.002
05/10/01	X	0.015		0.007	X	0.005	X	**0**		**0**		0.003	X	0.003		0.003	X	0.002	X	0.016	X	0.002		0.002
05/24/01	X	0.015		0.014		0.005	X	**0**		**0**		0.003	X	0.003		0.003	X	0.002	X	0.017	X	0.002	X	0.002
06/07/01	X	0.019		0.014		0.005	X	0.002		**0**		0.003	X	0.004	X	0.008	X	0.003	X	0.015		0.003	X	0.003
06/21/01		0.016		0.013	X	0.005	X	0.002		**0**		0.003	X	0.003	X	0.006	X	0.003	X	0.015	X	0.003	X	0.003
07/05/01	X	0.011		0.012		0.005	X	0.002		**0**		0.003	X	0.002		0.003	X	0.003	X	0.012	X	0.002	X	0.002
07/19/01	X	0.011		0.013		0.004	X	**0**		**0**		0.003	X	0.003		0.003	X	0.002	X	0.012	X	0.002	X	0.002
08/02/01	X	0.014		0.013		0.005	X	**0**		**0**		0.003	X	0.003		0.003	X	0.002	X	0.014	X	**0**	X	0.002
08/16/01	X	0.009		0.011	X	0.004	X	**0**		**0**		0.003	X	0.002	X	0.004	X	0.002	X	0.012	X	0.002		**0**
08/30/01	X	0.013		0.012		0.005	X	**0**		**0**		0.003	X	0.003		0.003	X	0.002	X	0.014		0.002	X	0.002
09/13/01	X	0.015		0.012	X	0.004	X	0.002		0.002		0.004	X	0.003		0.003	X	0.002	X	0.014	X	0.002	X	0.002
09/27/01		0.003		0.003		**0**		**0**		**0**		0.003		**0**		0.002	X	0.002		0.004		0.002	X	0.002
10/11/01		0.013		0.014		0.004	X	**0**		**0**		0.003	X	0.003		0.003	X	0.002	X	0.014	X	0.002	X	0.002
10/25/01	X	0.015		0.015		0.004	X	0.002		**0**		**0**	X	0.003		0.003	X	0.002		0.005		0.005	X	0.002
11/08/01		0.009		0.014		0.003	X	0.002		0.002		0.002	X	0.002		0.003	X	0.002		0.013	X	0.002	X	0.003
11/22/01	X	0.007		0.013	X	0.004	X	**0**		**0**		0.002	X	0.002		0.003	X	0.002		0.009	X	0.002	X	0.002
12/08/01		0.003		0.002	X	0.003	X	**0**		**0**		**0**	X	0.002		**0**	X	0.002	X	0.004	X	0.002	X	0.002
Total	27		1		21		31		0		2		31		5		31		27		28		30	

Table 13. Dissolved solute export from the Taconazo watershed calculated for an 8.5- day period (06/27/03 000 to 7/5/03 1200) using the weekly approach and the regression approach in comparison with an estimate of "true" solute export determined using products of concentration and discharge over many small time intervals (Figure 26)

The dissolved export for each solute is expressed in moles. The weekly approach was calculated three times for the same time period by using samples collected at three different stream discharge rates varying from baseflow (2.67 m^3/min) to mid-flow (7.70 m^3/min) to high flow (16.20 m^3/min).

	"True" Export	**Regression Method Export**	**Weekly Method Export**		
			Baseflow	Mid flow	High flow
Cl	2,411	2,484	2,578	2,212	1,366
SO_4	113	139	95	98	112
Na	3,263	3,257	3,614	3,127	2,202
K	668	629	540	665	641
Mg	563	564	530	527	370
Ca	747	709	738	682	596

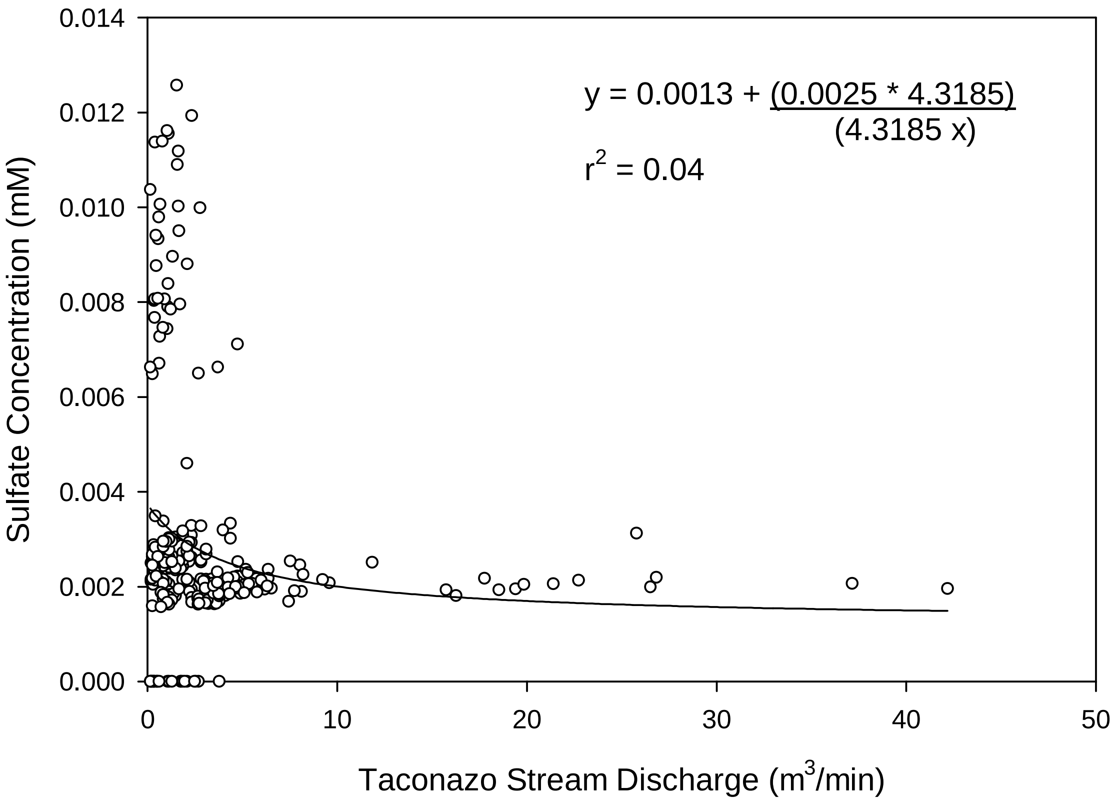


Figure 20. Sulfate concentrations for samples collected at the Taconazo weir plotted against stream discharge.

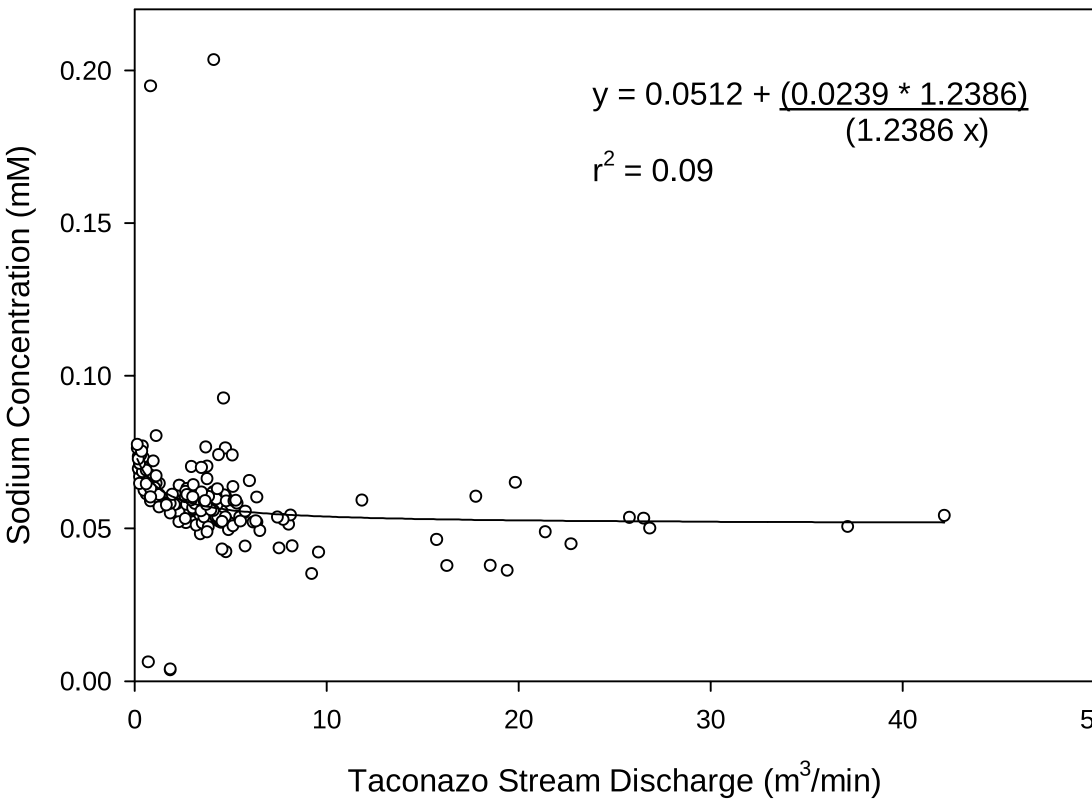


Figure 21. Sodium concentrations for samples collected at the Taconazo weir plotted against stream discharge.

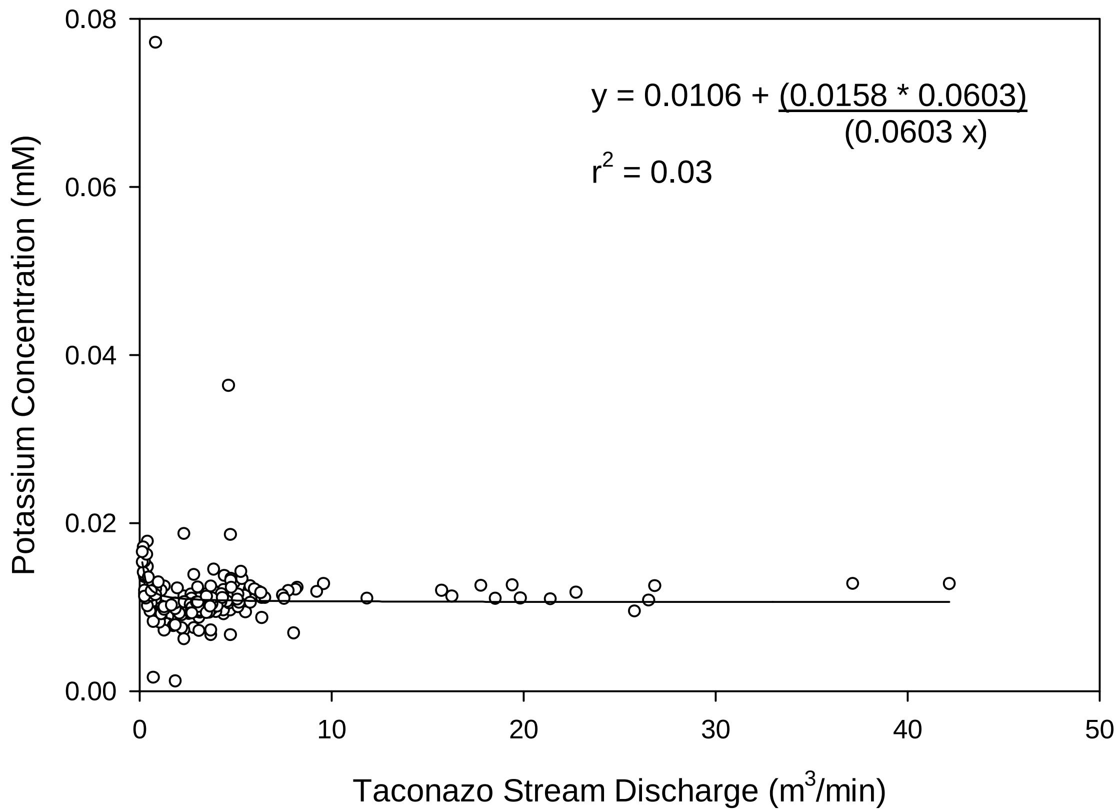


Figure 22. Potassium concentrations for samples collected at the Taconazo weir plotted against stream discharge.

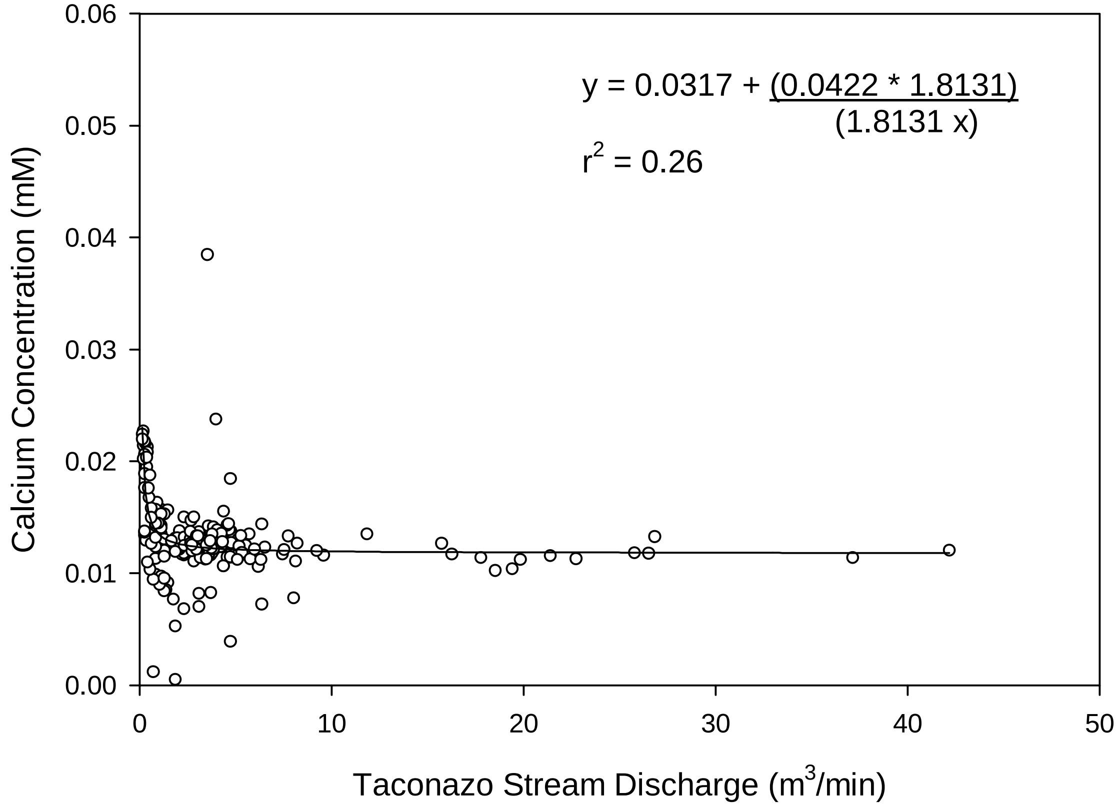


Figure 23. Calcium concentrations for samples collected at the Taconazo weir plotted against stream discharge.

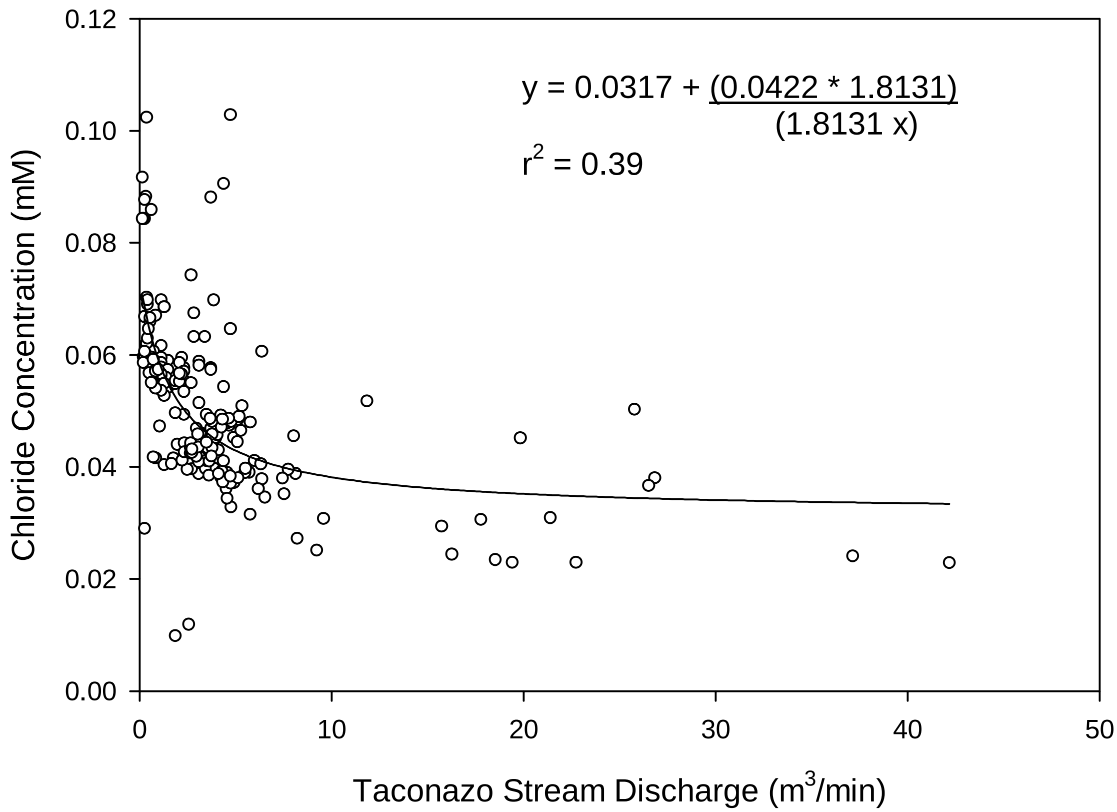


Figure 24. Chloride concentrations for samples collected at the Taconazo weir plotted against stream discharge.

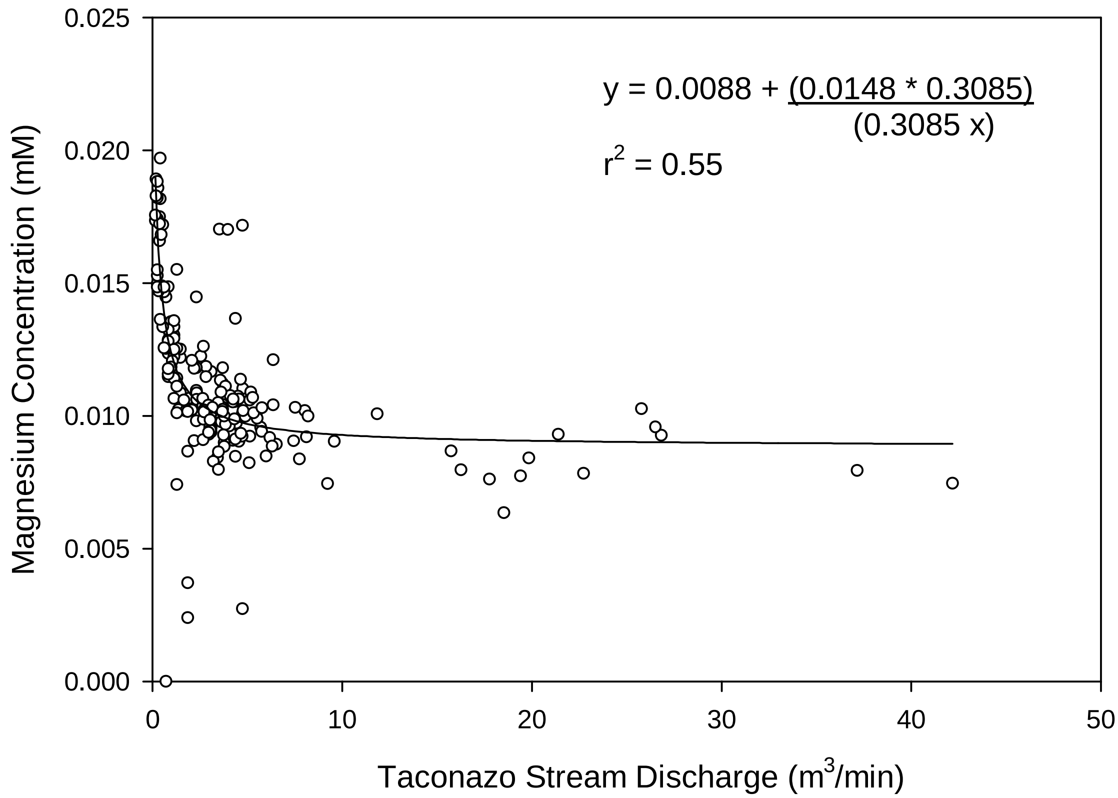


Figure 25. Magnesium concentrations for samples collected at the Taconazo weir plotted against stream discharge.

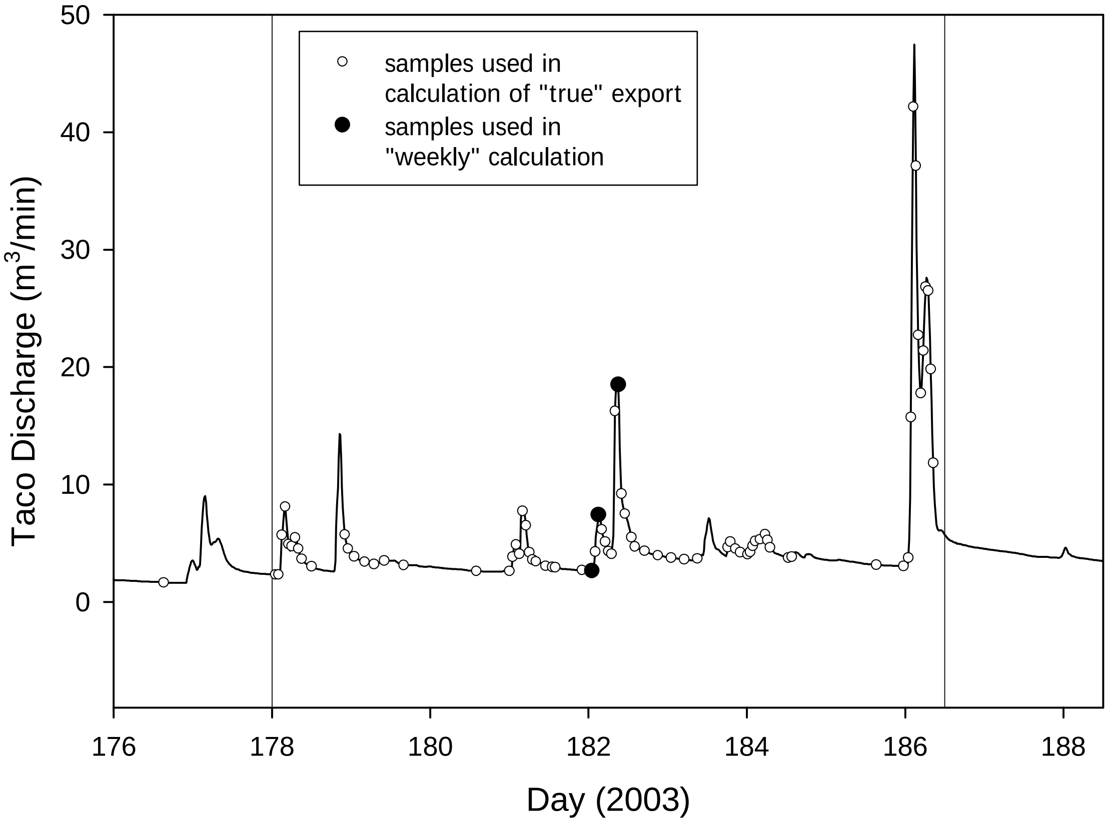
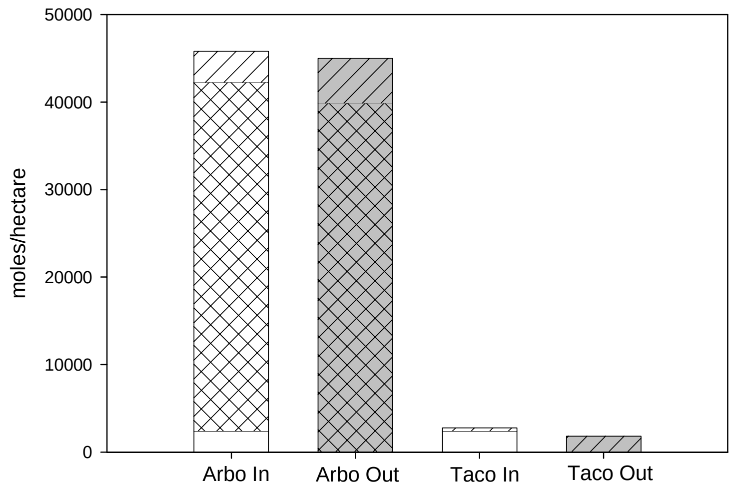


Figure 26. Samples collected at the Taconazo weir used in the calculation of "true" solute export (as discussed in Section 5.3) for comparison with export from the weekly and regression approaches.

True export was calculated for an 8.5-day period (06/27/03 000 to 7/5/03 1200). The weekly approach was calculated three times for the same time period by using samples collected at three different stream discharge rates varying from baseflow (2.67 m^3/min) to mid-flow (7.70 m^3/min) to high flow (16.20 m^3/min).

12/00 to 11/01



12/01 to 11/02

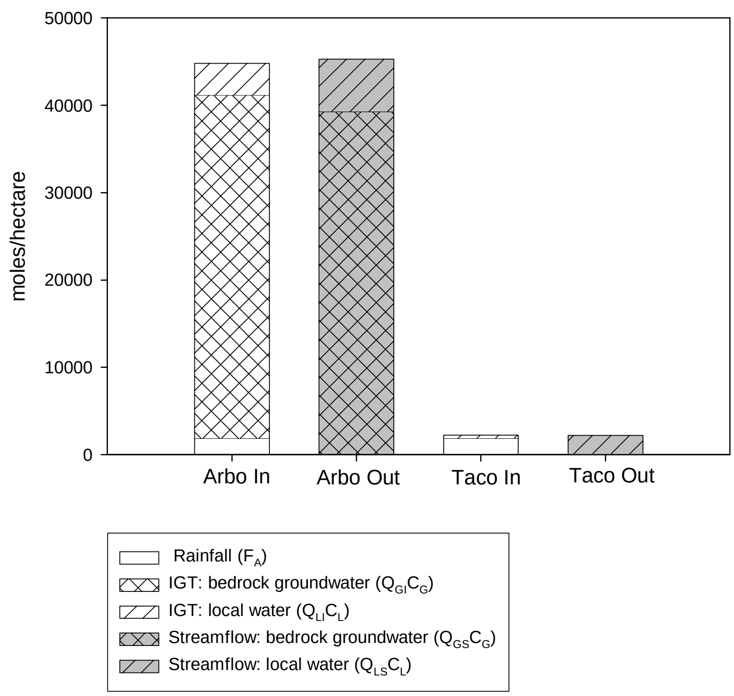
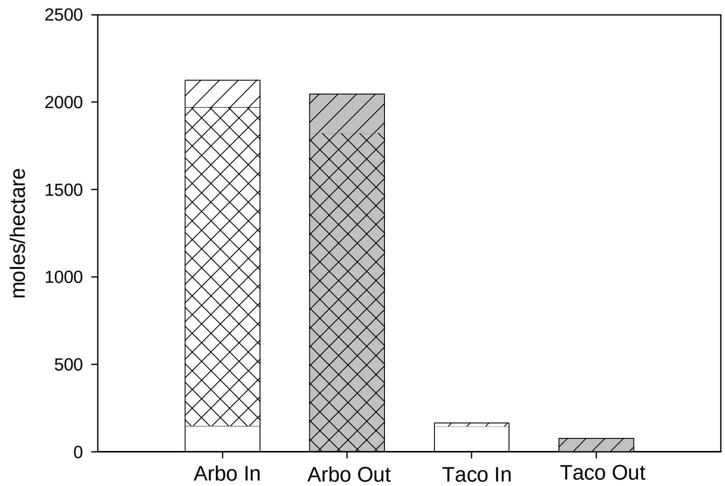


Figure 27. Annual chloride budgets for the Taconazo and Arboleda watersheds for 12/00 to 11/01 and 12/01 to 11/02.

The inputs to the Arboleda and Taconazo watersheds are labeled Arbo In and Taco In, respectively. The outputs from the Arboleda and Taconazo watersheds are labeled Arbo Out and Taco Out, respectively. The inputs and outputs were normalized by the area of each watershed to allow for direct comparison.

12/00 to 11/01



12/01 to 11/02

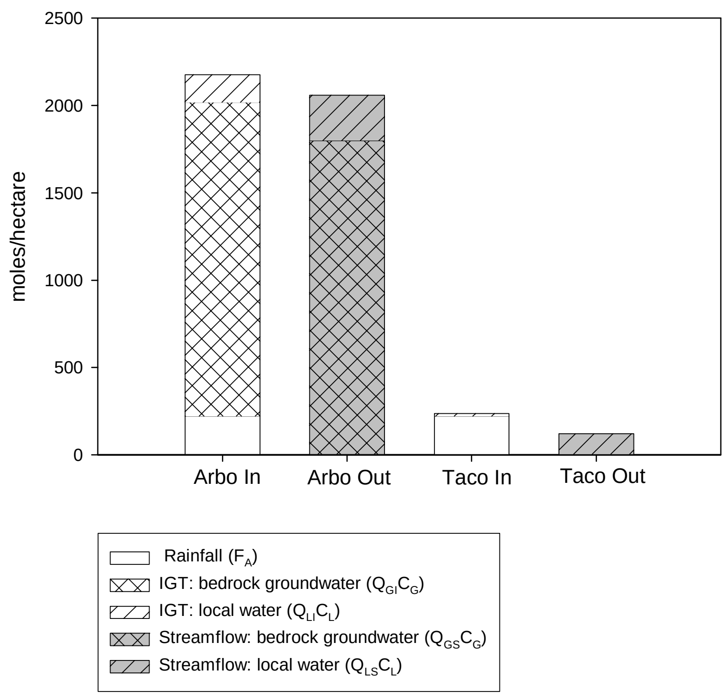
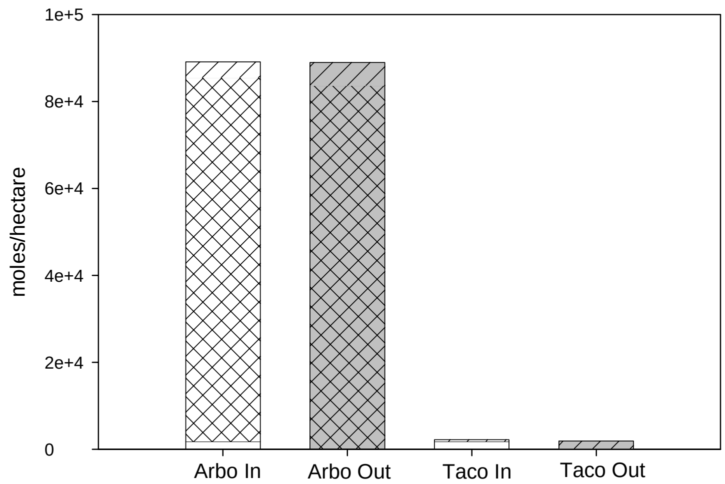


Figure 28. Annual sulfate budgets for the Taconazo and Arboleda watersheds for 12/00 to 11/01 and 12/01 to 11/02.

The inputs to the Arboleda and Taconazo watersheds are labeled Arbo In and Taco In, respectively. The outputs from the Arboleda and Taconazo watersheds are labeled Arbo Out and Taco Out, respectively. The inputs and outputs were normalized by the area of each watershed to allow for direct comparison.

12/00 to 11/01



12/01 to 11/02

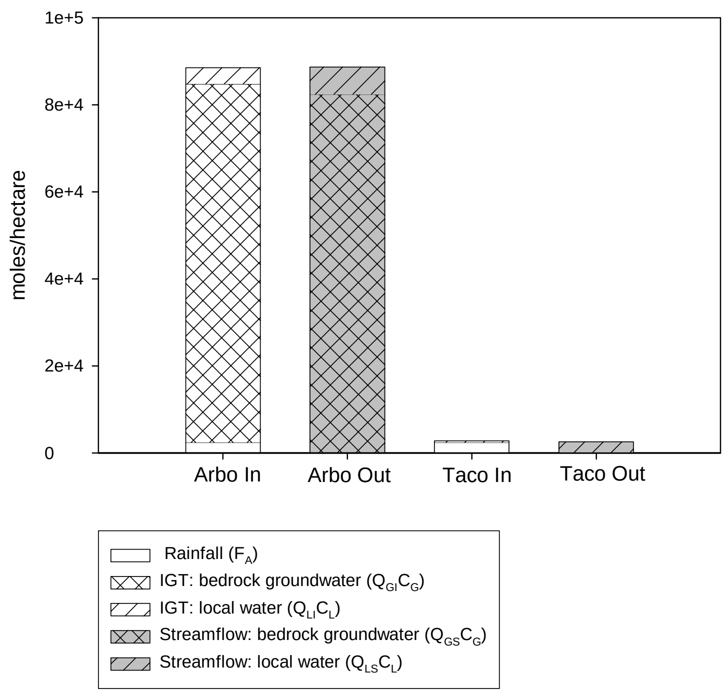


Figure 29. Annual sodium budgets for the Taconazo and Arboleda watersheds for 12/00 to 11/01 and 12/01 to 11/02.

The inputs to the Arboleda and Taconazo watersheds are labeled Arbo In and Taco In, respectively. The outputs from the Arboleda and Taconazo watersheds are labeled Arbo Out and Taco Out, respectively. The inputs and outputs were normalized by the area of each watershed to allow for direct comparison.

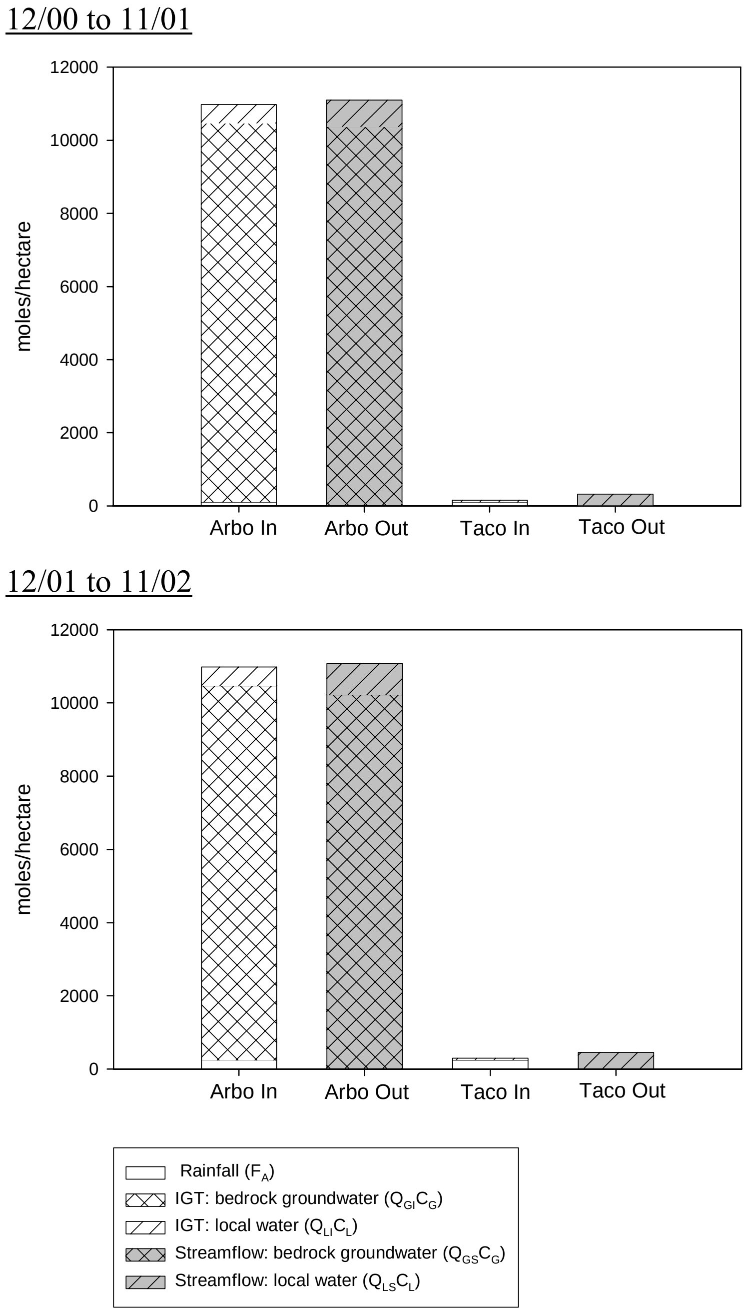
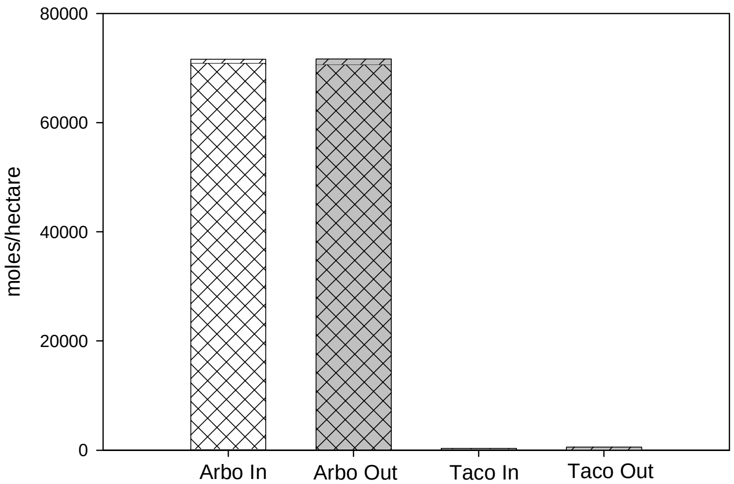


Figure 30. Annual potassium budgets for the Taconazo and Arboleda watersheds for 12/00 to 11/01 and 12/01 to 11/02.

The inputs to the Arboleda and Taconazo watersheds are labeled Arbo In and Taco In, respectively. The outputs from the Arboleda and Taconazo watersheds are labeled Arbo Out and Taco Out, respectively. The inputs and outputs were normalized by the area of each watershed to allow for direct comparison.

12/00 to 11/01



12/01 to 11/02

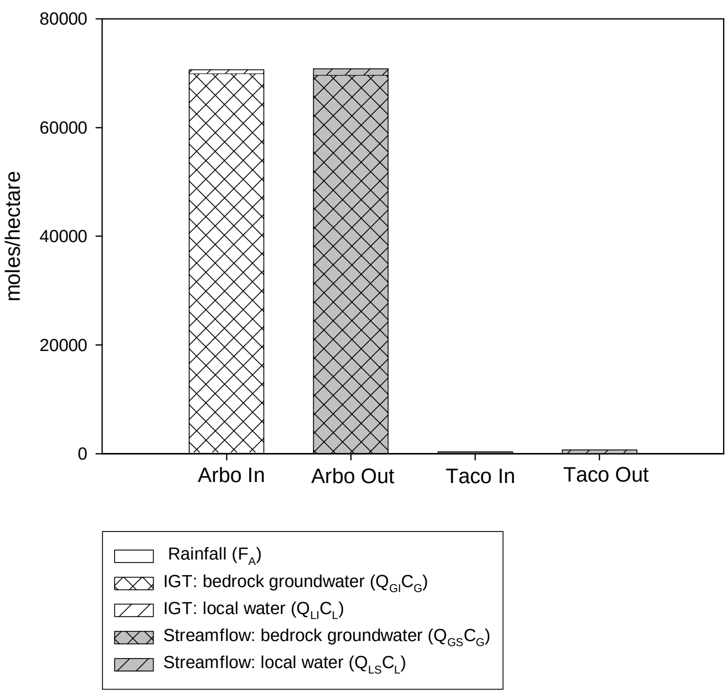
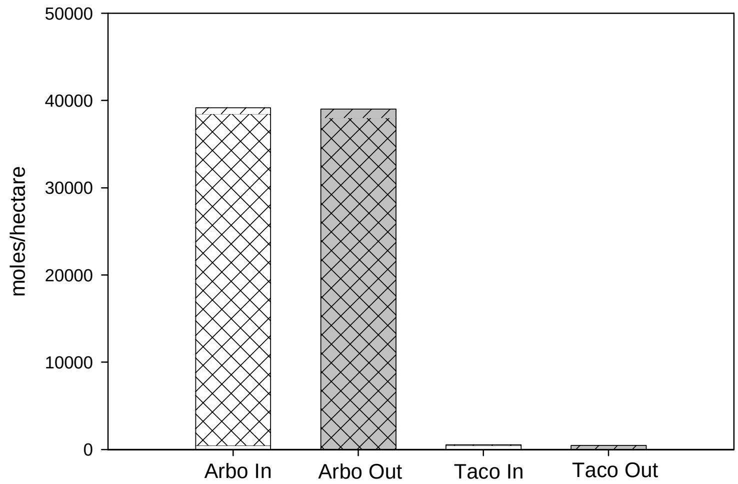


Figure 31. Annual magnesium budgets for the Taconazo and Arboleda watersheds for 12/00 to 11/01 and 12/01 to 11/02.

The inputs to the Arboleda and Taconazo watersheds are labeled Arbo In and Taco In, respectively. The outputs from the Arboleda and Taconazo watersheds are labeled Arbo Out and Taco Out, respectively. The inputs and outputs were normalized by the area of each watershed to allow for direct comparison.

12/00 to 11/01



12/01 to 11/02

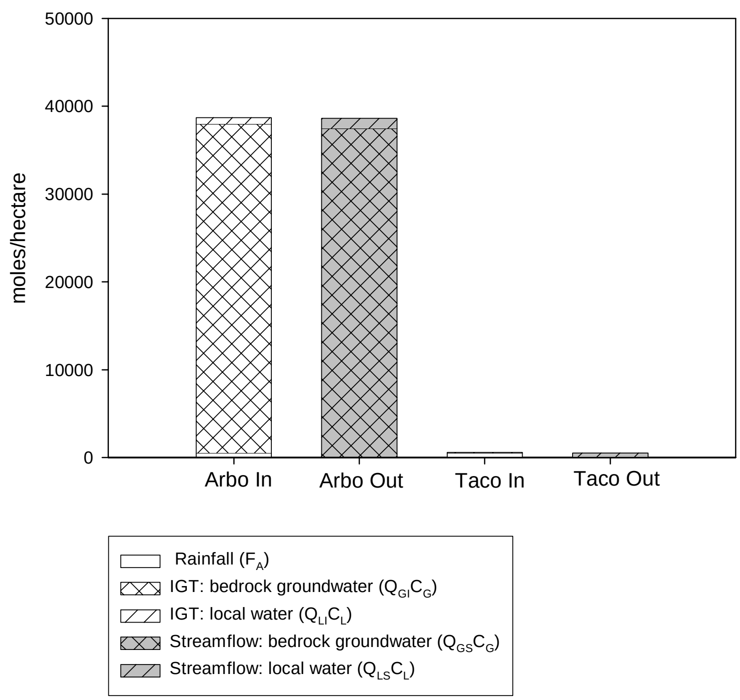


Figure 32. Annual calcium budgets for the Taconazo and Arboleda watersheds for 12/00 to 11/01 and 12/01 to 11/02.

The inputs to the Arboleda and Taconazo watersheds are labeled Arbo In and Taco In, respectively. The outputs from the Arboleda and Taconazo watersheds are labeled Arbo Out and Taco Out, respectively. The inputs and outputs were normalized by the area of each watershed to allow for direct comparison.

Chapter 6: CONCLUSIONS

The most noticeable outcome of the water budgets was the difference in stream discharge between the two watersheds that resulted from IGT of bedrock groundwater and local water into the Arboleda watershed. It is important to note that the discharge of bedrock groundwater IGT could not be detected with physical data alone and that local water IGT could not be detected through the use of chemical data alone. Physical hydrologic data alone would allow total IGT (mm/year) to be quantified in the context of the water budget, but the combination of physical and chemical data together allowed the IGT to be quantitatively separately into two components (bedrock groundwater and local water).

Together, the IGT of local water and bedrock groundwater result in the Arboleda having approximately three times the water flux in and out of the watershed when compared to the Taconazo. The Taconazo does not have any indication of bedrock groundwater IGT discharging in the watershed. However, it is likely that the watershed receives a small amount of local water IGT.

The most noticeable outcome of the chemical budgets was the large solute flux into and out of the Arboleda watershed. The Arboleda watershed receives an average of 11 (SO4) to 220 (Mg) times more solute input than the Taconazo watershed. Total solute input to the Arboleda watershed is dominated by bedrock groundwater, which accounts for an average of 84 (SO4) to 99 (Mg) percent of solute input, as compared with the Taconazo watershed where total solute input is controlled by rainfall accounting for an average of 73 (K) to 91 (SO4) percent of solute input. The remaining small portion of solute input to the Taconazo watershed (i.e., the portion not due to rainfall) is from the IGT of local water whereas the remaining portion in the Arboleda watershed (i.e., the portion not due to bedrock groundwater) is due to roughly equal amounts of rainfall and IGT of local water.

The increased solute export from the Arboleda is also primarily due to bedrock groundwater. The Arboleda watershed discharges an average of 22 (SO_4) to 116 (Mg) times more solutes than the Taconazo watershed. Solute export from the Arboleda watershed is dominated by bedrock groundwater, which accounts for 88 (Cl and SO_4) to 98 (Mg) percent of solute export with the remaining portion of solute export being comprised of local water. In comparison, all solute export from the Taconazo watershed is local water.

The extreme difference between the two watersheds for the water budgets and the chemical budgets is due to IGT of local water and bedrock groundwater into the Arboleda watershed. The large quantities of solutes discharged into and exported out of the Arboleda watershed are not observed in other published small budget studies. None of the 25 chemical budget studies at tropical sites that were compared and summarized by Bruijnzeel (1991) showed evidence for the discharge of such large quantities of IGT, though Bruijnzeel concluded from the budget results that four of the 25 sites received a small amount of IGT. Additional budget studies (Williams and Melack 1997; Stoorvogel et al. 1997; McDowell and Asbury 1994; Lesack 1993b) published since the summary by Bruijnzeel also do not indicate the presence of IGT discharge as is seen in the Arboleda watershed.

Though IGT has not been widely observed in small budget studies, the Arboleda watershed is hardly a unique situation. IGT was previously detected in studies in Texas (Darling et al. 1997) and in the Western U.S. (Thyne et al. 1999; Johannesson et al. 1995, 1997). Large solute variations in adjacent streams were believed to be due to groundwater discharge near several Costa Rican volcanoes (Barva, Poas, and Arenal) (Pringle et al. 1993). Additionally, there is convincing evidence that IGT is discharging in several watersheds at La Selva (in addition to the Arboleda) including the Salto and the Sura based on their stream chemistry (Genereux et al. 2002).

The large quantities of solutes discharged into the Arboleda, but not the Taconazo are not fully understood. It is likely that underlying geological heterogeneities are influencing the path of water discharging from the regional groundwater flow system. The Arboleda watershed obviously has a much better connection with the regional flow system. While specific evidence is not available to evaluate how and/or why the Arboleda is better connected to the regional groundwater system than the Taconazo, several possibilities exist including variation in the local volcanic stratigraphy or a connection through faults or large dikes.

The connection of the Arboleda watershed to the regional groundwater system demonstrates the importance of carefully making assumptions in small watershed studies. Most budget studies are conducted on the assumption that watershed is ‘tight’. The results of this study clearly indicate the danger in making such an assumption. In the chemical budget studies reviewed by Bruijnzeel (1991), he identified four sites that may have had deep groundwater leakage (i.e., IGT recharge) through joints, fault zones, or alluvial deposits. By not accounting for IGT, the original results of one study reviewed by Bruijnzeel (1991) showed a net gain of Ca, Mg, and K, but an alternate computation by Bruijnzeel that accounted for the basin leakage indicated net losses for Ca, Mg, and K.

The results of this study clearly indicate that the traditional small watershed approach to water and chemical budgets needs to be modified to consider IGT. Small watershed studies are a major research "tool" in hydrology, ecology, and geochemistry. If this approach is to be used successfully, several items need to be considered. Water budget studies would ideally be coupled with chemical budget studies or at the very least they should include collection of water samples for chemical analysis. In the case of this study, bedrock groundwater IGT could not be detected (or quantified) without chemical data. The results of this study also show the importance of measuring all the fluxes. Several water budget studies typically calculate change in groundwater or evapotranspiration as a residual rather than measuring it. If a similar approach were taken in this study, it would not have been possible to quantify local water IGT, which was a significant input to the Arboleda watershed.

This study also highlights the need for small budget studies to consider IGT because of its potential to dominate other characteristics (e.g. climate, vegetation, soils, geology, topography) of the watershed producing major differences in water and solute fluxes. Depending on the spatial variability of the connection to a regional groundwater system, adjacent watersheds with similar characteristics (such as the Arboleda and Taconazo), which would be expected to have similar water and solute exports, could be drastically different. Without accounting for the possibility of IGT, it is nearly impossible to make any generalizations on water and chemical fluxes for small watersheds.

Small watershed studies should also account for IGT because any land use changes such as deforestation in the recharge area (which has not yet been defined for the study site) may significantly affect the quantity and quality of water discharged in the small watersheds.

The discharge of interbasin groundwater transfer in lowland areas influences both the terrestrial and aquatic ecology by providing significant quantities of water and solutes to streams, seeps, and riparian wetlands. The discharge of bedrock groundwater IGT at La Selva has elevated phosphorus levels (Pringle et al. 1990) that were shown to increase rates of algal growth (Pringle and Triska 1991) and microbially mediated decomposition (Rosemond et al. 2001; Ramirez 2000). The water input to watersheds can also maintain the hydrologic conditions needed to support wetlands (Genereux et al. 2002).

In order to protect tropical forests, Bruijnzeel (1990) recommended using watersheds as principal planning units, which would allow for the effects of environmental impacts on hydrology to be evaluated within a natural framework. While this is a good start, it is not nearly enough by itself. Full protection of lowland rainforests, such as the study watersheds, requires an understanding of the regional groundwater system. Additionally, protection requires a thorough knowledge of the extent of the connection between the watershed and regional flow system. This underscores the importance of regional land use planning based on accurate knowledge of recharge and discharge areas in order to protect ecosystems and human populations. Several different approaches can be used to identify the recharge areas including the use of head data; recharge elevations can be estimated based on ^{18}O data.

REFERENCES

Abdul Rahim and Zulkifli Yusop. 1986. Stream water quality of undisturbed forest catchments in peninsular Malaysia. In Hadi, Y. and K. Awang, N.M. Majid, and S. Mohamed (eds.). Impact of man's activities on tropical upland forest ecosystems. University Pertanian Malaysia Press: Serdang, Malaysia. Pp. 289-308.

Alvarado Induni, G.E. 1990. Caracteristicas geologicas de la Estacion Biologica La Selva, Costa Rica. Tecnologia 10: 11-22.

Bormann, F.H., D.W. Fisher, and R.S. Pierce. 1969. A working model for the variation in stream water chemistry at the Hubbard Brook Experimental Forest, New Hampshire. Water Resources Research 5: 1353-1363.

Bormann, F.H., G.E. Likens, T.G. Siccama, R.S. Pierce, J.S. Eaton. 1974. The export of nutrients and recovery of stable conditions following deforestation at Hubbard Brook. Ecological Monographs 44: 255-277.

Bourgeois, W.W., D.W. Cole, H. Riekerk, and S.P. Gessel. 1972. Geology and soils of comparative ecosytem study areas, Costa Rica. Tropical Forestry Series: 11, Institute of Forest Products, University of Washington, Seattle.

Brinkmann, W.L.F. 1983. Nutrient balance of a central Amazonian rainforest: comparison of natural and man-managed systems. International Association of Hydrological Sciences Publication 140: 153-163.

Brinkmann, W.L.F. 1985. Studies on hydrobiogeochemistry of a tropical lowland forest system. Geojournal 11: 89-101.

Bruijnzeel, L.A. 1983. The chemical mass balance of a small basin in a wet monsoonal environment and the effect of a fast-growing plantation forest. International Association of Hydrological Sciences Publication 141: 229-239.

Bruijnzeel, L.A. 1989. Nutrient content of bulk precipitation in south-central Java, Indonesia. Journal of Tropical Forest Science 1: 145-161.

Bruijnzeel, L.A. 1990. Hydrology of moist tropical forests and effects of conversion: a state of knowledge review. International Association of Hydrological Sciences: 1-224.

Bruijnzeel, L.A. 1991. Nutrient input-output budgets of tropical forest ecosystems: a review. Journal of Tropical Ecology 7: 1-24.

Calder, I.R., I.R. Wright, and D. Murdiyarso. 1986. A study of evaporation from tropical rain forest-West Java. Journal of Hydrology 89: 13-31.

Cavelier, J., M. Jaramillo, D. Solis, D. de Leon. 1997. Water balance and nutrient inputs in bulk precipitation in tropical montane cloud forest in Panama. Journal of Hydrology 193: 83-96.

Cey, E.E., D.L. Rudolph, G.W. Parkin, and R. Aravena. 1998. Quantifying groundwater discharge to a small perennial stream in southern Ontario, Canada. Journal of Hydrology 210: 21-37.

Cook, P.G., T.J. Hatton, D. Pidsley, A.L. Herczeg, A. Held, A. O'Grady, D. Eamus. 1998. Water balance of a tropical woodland ecosystem, Northern Australia: a combination of micro-meteorological, soil physical and groundwater chemical approaches. Journal of Hydrology 210: 161-177.

Darling, B.K., B.J. Hibbs, A.R. Dutton and J.M. Sharp, Jr. 1997. Interbasin groundwater flow in trans-

Pecos Texas. Geological Society of American Abstracts with Programs 29: 7.

DeBruin, H.A.R. 1983. Evapotranspiration in humid tropical regions. In: Hydrology of humid tropical regions with particular reference to the hydrological effects of agriculture and forestry practice. IAHS Publication No. 40.

Dickey, David. 2003. Personal communication.

Dingman, S.L. 2002. Physical Hydrology. Prentice Hall, New Jersey.

Edmunds, W.M., J.J. Carrillo-Rivera, and A. Cardona. 2002. Geochemical evolution of groundwater beneath Mexico City. Journal of Hydrology 258: 1-24.

Eklund, T.J., W.H. McDowell, and C.M. Pringle. 1997. Seasonal variation of tropical precipitation chemistry: La Selva, Costa Rica. Atmospheric Environment 31: 3903-3910.

Fetter, C.W. 2001. Applied hydrogeology. Prentice Hall, Upper Saddle River, New Jersey.

Flerchinger, G.N. and K.R. Cooley. 2000. A ten-year water balance of a mountainous semi-arid watershed. Journal of Hydrology 237: 86-99.

Galloway, JN and GE Likens. 1978. The collection of precipitation for chemical analysis. Tellus 30: 71-82.

Genereux, D.P., and H.F. Hemond, and P.J. Mulholland. 1993. Spatial and temporal variability in streamflow generation on the West Fork of Walker Branch Watershed. Journal of Hydrology 142: 137-166.

Genereux, D.P. and C.M. Pringle. 1997. Chemical mixing model of streamflow generation at La Selva Biological Station, Costa Rica. Journal of Hydrology 199: 319-330.

Genereux, D.P. 1998. Quantifying uncertainty in tracer-based hydrograph separations. Water Resources Research 34: 915-919.

Genereux, D.P., S.J. Wood, and C.M. Pringle. 2002. Chemical tracing of interbasin groundwater transfer in the lowland rainforest of Costa Rica. Journal of Hydrology 258: 163-178.

Genereux, D.P. 2003. Comparison of naturally-occurring chloride and oxygen-18 as tracers of interbasin groundwater transfer in lowland rainforest, Costa Rica. Submitted to the Journal of Hydrology.

Hartshorn, G.S. and B.E. Hammel. 1994. Vegetation Types and Floristic Patterns, In: L.A. McDade, K.S. Bawa, H.A. Hespenheide, and G.S. Hartshorn (eds.), La Selva: Ecology and Natural History of a Neotropical Rainforest, The University of Chicago Press, Chicago, Illinois, USA.

Holscher, D., T.D. de A. Sa, T.X. Bastos, M. Denich, and H. Folster. 1997. Evaporation from young secondary vegetation in eastern Amazonia. Journal of Hydrology 193: 293-305.

Horng, F.W., Y.J. Hsia, H.B. King, and B.Y. Yang. 1985. Biogeochemistry of a Small Hardwood Forested Watershed Soil and Fertilizer in Taiwan, Society of Soil and Fertilizer Science, Taipei, Taiwan.

Johannesson, K.H., X. Zhou and K.J. Stetzenbach. 1995. Rare earth element distributions in groundwaters and evidence of interbasin flow in the desert southwest. Geological Society of America Abstracts with Programs 27: A96.

Johannesson, K.H., K.J. Stetzenbach and V.F. Hodge. 1997. Rare earth elements as geochemical tracers of regional groundwater mixing. Geochimica et Cosmochimica Acta 61: 3605-3618.

Johnson, A.I. 1967. Specific Yield- Compilation of Specific Yields for Various Materials. U.S. Geological Survey Water Supply Paper 1662-D, p. D1-D74.

Johnson, D.W., D.W. Cole, and S.P. Gessel. 1979. Acid precipitation and soil sulfate adsorption properties in a tropical and in a temperate forest soil. Biotropica 11(1): 38-42.

Johnson, D.W. and R.I. Hook. 1989. Analysis of biogeochemical cycling processes in Walker Branch Watershed. Springer, New York.

Johnson, N. and R.A. Parnell Jr. 1986. Composition, distribution and neutralization of "acid rain" derived from Masaya volcano, Nicaragua. Tellus 38B: 106-117.

Kehew, A.E. 2001. Applied chemical hydrogeology. Prentice Hall, Upper Saddle River, New Jersey.

Kenworthy, J.B. 1971. Water and nutrient cycling in a tropical rainforest, pages 49-65. In: J.R. Flenley, Editor, The Water Relations of Malesian Forests Miscellaneous Series no. 11, University of Hull, Department of Geography, Hull.

Klinge, R. and J. Schmidt, and H. Folster. 2001. Simulation of water drainage of a rain forest and forest conversion plots using a soil water model. Journal of Hydrology 246: 82-95.

Lam, K.C. 1978. Soil erosion, suspended sediment and solute production in three Hong Kong catchments. The Journal of Tropical Geography 47: 51-62.

Lesack, L.F.W. 1993a. Water balance and hydrologic characteristics of a rain forest catchment in the central Amazon basin. Water Resources Research 29: 759-773.

Lesack, L.F.W. 1993b. Export of nutrients and major ionic solutes from a rain forest catchment in the central Amazon basin. Water Resources Research 29: 743-758.

Lesack, L.F.W and J.M. Melack. 1995. Flooding hydrology and mixture dynamics of lake water derived from multiple sources in an Amazon floodplain lake. Water Resources Research 31: 329-345.

Lesack, F.W. and J.M. Melack. 1996. Mass balance of major solutes in a rainforest catchment in the Central Amazon: Implications for nutrient budgets in tropical rainforests. Biogeochemistry 32: 115-142.

Lewis, W.M. Jr., S.K. Hamilton, S.L. Jones, and D.D. Runnels. 1987. Major element chemistry, weathering and element yields for the Caura River drainage, Venezuela. Biogeochemistry 4: 59-81.

Lewis, W.M. Jr. 1986. Nitrogen and phosphorous runoff losses from a nutrient-poor tropical forest moist forest. Ecology: 67: 275-1282.

Lide, D.R. (ed.). 1994. CRC Handbook of Chemistry and Physics, 75th edition. CRC Press, Boca Raton.

Likens, G.E. and Bormann, F.H. 1995. Biogeochemistry of a Forested Ecosystem, Springer-Verlag, New York.

Locsey, K. L. and M. E. Cox. 2003. Statistical and hydrochemical methods to compare basalt- and basement rock-hosted groundwaters: Atherton Tablelands, north-eastern Australia. Environmental Geology 43: 698-713.

Loescher, H. W. 2002. Ecosystem-level responses of carbon and energy from a tropical wet forest in Costa Rica. Ph.D. dissertation, University of Florida.

Luvall, J.C. 1984. Tropical deforestation and recovery: the effects on evaporation processes. Ph.D. dissertation. University of Georgia.

Luxmoore, R.J. and D.D. Huff. 1989. Water, pages 164-196. In: D.W. Johnson and R.I. van Hook, Editors, Analysis of Biogeochemical Cycling Processes in Walker Branch Watershed, Springer, New York.

Malmer, A. 1996. Hydrological effects and nutrient losses of forest plantation establishment on tropical rainforest land in Sabah Malaysia. Journal of Hydrology 174: 129-148.

McDade, L. and G.S. Hartshorn. 1994. La Selva Biological Station, In: L.A. McDade, K.S. Bawa, H.A. Hespenheide, and G.S. Hartshorn (eds.), La Selva: Ecology and Natural History of a Neotropical Rainforest, The University of Chicago Press, Chicago, Illinois, USA.

McDowell, W.H. 2003. Personal communication.

McDowell, W.H. and C.E. Asbury. 1994. Export of carbon, nitrogen, and major ions from three tropical montane watersheds. Limnology and Oceangraphy 39: 111-125.

Melack, J.M., J.O. Sickman, and A. Leydecker. 1998. Comparative Analyses of High-Altitude Lakes and Catchments in the Sierra Nevada: Susceptibility to Acidification. Contract A032-188. California Environmental Protection Agency, Air Resources Board, Sacramento.

Myerson, R.B. 2000. VBA code for Simtools.xla (3.31) and Formlist.xla (1.5). (http://home.uchicago.edu/~rmyerson/addins.htm). University of Chicago.

Observatorio Vulcanologico y Sismologico de Costa Rica, Universidad Nacional (OVSICORI-UNA), Apartado 86-3000, Heredia, Costa Rica. (http://www.una.ac.cr/ovsi/). Checked August 13, 2003.

Parker, G.G. 1985. The effect of disturbance on water and solute budgets of hillslope tropical rainforest in northeastern Costa Rica. Ph.D. dissertation. University of Georgia.

Priestly, C.H.B. and R.J. Taylor. 1972. On the assessment of the surface heat flux and evaporation using large scale parameters. Monthly Weather Review 100: 81-92.

Pringle, C.M., P. Paaby-Hansen, P.D. Vaux, and C.R. Goldman. 1986. In situ nutrient assays of periphyton growth in a lowland Costa Rican stream. Hydrobiologia 134:207-213.

Pringle, C.M., F.J. Triska, and G. Browder. 1990. Spatial variation in basic chemistry of streams draining a volcanic landscape on Costa Rica's Caribbean slope. Hydroiologia 206: 73-85.

Pringle, C.M. and F.J. Triska. 1991. Effects of geothermal groundwater on nutrient dynamics of a lowland Costa Rican stream. Ecology 72: 951-965.

Pringle, C.M., G.L. Rowe, F.J. Triska, J.F. Fernandez, and J. West. 1993. Landscape linkages between geothermal activity, solute composition, and ecological response in streams draining Costa Rica's Atlantic slope. Limnology and Oceanography 38: 753-774.

Rahim, A. and Z. Yusop. 1986. Stream water quality of undisturbed forest catchments in peninsular Malaysia, pages 298-308. In: Y. Hadi, K. Awang, N.M. Majid and S. Mohamed, Editors, Impact of Man's Activities on Tropical Upland Forest Ecosystems, Universiti Pertanian Malaysia Press, Serdang, Malaysia.

Ramirez, A., C.M. Pringle, and L. Molina. 2003. Effect of stream phosphorus levels on microbial respiration. Freshwater Biology 48: 88-97.

Ramirez, A. 2000. Control of benthic assemblages in detritus-based tropical systems. PhD dissertation, Institute of Ecology, University of Georgia, Athens, Georgia, USA.

Rantz, S.E., and others. 1982. Measurement and computation of streamflow: volume 2. Computation of discharge. U.S. Geological Survey Water Supply Paper 2175, p. 285-631.

Richardson, J.L. and M.J. Vepraskas. 2001. Wetland Soils. Lewis Publishers, Washington D.C.

Rosemond, A.D., C.M. Pringle, A. Ramirez, M.J. Paul, and J.L. Meyer. 2002. Landscape variation in phosphorous concentration and effects on detritus-based tropical streams. Limnology and Oceanography 47(1): 278-289.

Rosemond, A.D., C.M. Pringle, A. Ramirez, and M.J. Paul. 2001. A test of top-down and bottom up control in a detritus-based food web. Ecology 82 (8): 2279-2293.

Rosenberg, N.J., B.L. Blad, and S.B. Verma. 1983. Microclimate the biological environment. John Wiley and Sons, New York.

Salmon, C.D., M.T. Walter, L.O. Hedin, and M.G. Brown. 2001. Hydrological controls on chemical export from an undisturbed old-growth Chilean forest. Journal of Hydrology 253: 69-80.

Sancho, F. and R. Mata. 1987. Estudio detallado de suelos. Estacion Biologica "La Selva." Report, Organization for Tropical Studies, San Jose, Costa Rica.

Sanford, R.L, P. Paaby, J.C. Luvall, and E. Phillips. 1994. Climate, Geomorphology, and Aquatic Systems, In: L.A. McDade, K.S. Bawa, H.A. Hespenheide, and G.S. Hartshorn (eds.), La Selva: Ecology and Natural History of a Neotropical Rainforest, The University of Chicago Press, Chicago, Illinois, USA.

Shuttleworth, W.J. 1988. Evaporation from Amazonian rainforest. Proceedings Royal Society London 233: 321-346.

Sickman, J.O, A. Leydecker, and J.M. Melack. 2001. Nitrogen mass balances and abiotic controls on N retention and yield in high-elevation catchments of the Sierra Nevada, California, United States. Water Resources Research 37: 1445-1461.

Soares, J.V. and A.C. Almeida. 2001. Modeling the water balance and soil water fluxes in a fast growing Eucalyptus plantation in Brazil. Journal of Hydrology 253: 130-147.

Sollins, P., F. Sancho, R. Mata, and R.L. Sanford, Jr. 1994. Soils and soil process research, In: L.A. McDade, K.S. Bawa, H.A. Hespenheide, and G.S. Hartshorn (eds.), La Selva: Ecology and Natural History of a Neotropical Rainforest, The University of Chicago Press, Chicago, Illinois, USA.

Stoorvogel, J.J., B.H. Janssen, and N. Van Breeman. 1997. The nutrient budgets of a watershed and its forest ecosystem in the Tai Nation Park in Cote d'Ivoire. Biogeochemistry 37: 159-172.

Sun, G., S.G. McNulty, D.M. Amatya, R.W. Skaggs, L.W. Swift Jr., J.P. Shepard, H. Riekerk. 2002. A comparison of the watershed hydrology of coastal forested wetlands and the mountainous uplands in the Southern US. Journal of Hydrology 263: 92-104.

Taylor, J.R. 1982. An introduction to error analysis: the study of uncertainties in physical measurements. University Science Books, Mill Valley, California.

Thyne, G.D., J.M. Gillespie and J.R. Ostdick. 1999. Evidence for interbasin flow through bedrock in the southeastern Sierra Nevada. Geological Society of America Bulletin 111: 1600-1616.

United States Department of Agriculture, Natural Resources Conservation Service. 1999. Soil taxonomy a basic system of soil classification for making and interpreting soil surveys, second edition: Agricultural Handbook No. 436.

Veneklass, E.J. 1990. Nutrient fluxes in bulk precipitation and throughfall in two montane tropical rain forests, Colombia. Journal of Ecology 78: 974-992.

Williams, M.R. and J.M. Melack. 1997. Solute export from forested and partially deforested catchments in the central Amazon. Biogeochemistry 38: 67-102.

Winograd, I.J. 1962. Interbasin movement of groundwater at the Nevada Test Site, Nevada. US Geological Survey Research: C108-C111.

Winter, T.C. 1981. Uncertainties in estimating the water balance of lakes, Water Resources Bulletin 17: 82-115.

Yusop, Z. 1989. Effects of selected logging methods on dissolved nutrient exports in Berembun watershed, peninsular Malaysia. Proceedings of the Regional Seminar on Tropical Forest Hydrology, Forest Research Institute Malaysia, Kepong, Malaysia.

Zulkifli Yusop, Abdul Rahim, Anhar Suki, and M. Fauzi Zakaria. 1989. Rainfall chemistry and nutrient loading in a Peninsular Malaysia forest site. Journal of Tropical Forest Science 1: 201-214.

APPENDICES

Appendix 1. Chemical analyses of stream samples collected at the Arboleda weir.

Q_S (in m3/min) represents the manual stage reading at the time of the sample collection (note: no readings were available from 9/8/98 through 2/14/00). All concentrations are in mM.

Date	Time	Q_S	Cl	SO_4	Na	K	Mg	Ca
09/08/98			0.4568	0.0537	0.8773	0.1240	0.7086	0.4924
09/16/98			0.4696	0.0493	0.8895	0.1284	0.7111	0.4942
09/22/98			0.4072	0.0451	0.7939	0.1128	0.6390	0.4486
09/30/98			0.4795	0.0506	0.9096	0.1280	0.7346	0.5138
10/06/98			0.4710	0.0493	0.9212	0.1291	0.7506	0.5186
10/13/98			0.3612	0.0417	0.7108	0.0990	0.5669	0.4029
10/20/98			0.3735	0.0387	0.7167	0.0998	0.5766	0.4090
10/27/98			0.4168	0.0436	0.8140	0.1151	0.6561	0.4617
11/03/98			0.4289	0.0479	0.8272	0.1164	0.6660	0.4672
11/10/98			0.3851	0.0378	0.7663	0.1053	0.6143	0.4337
11/18/98			0.4109	0.0419	0.8034	0.1137	0.6486	0.4578
11/24/98			0.4251	0.0461	0.8525	0.1175	0.6927	0.4822
12/01/98			0.3709	0.0380	0.7288	0.1032	0.5871	0.4181
12/08/98			0.3853	0.0386	0.7623	0.1055	0.6095	0.4321
12/14/98			0.3696	0.0348	0.7467	0.1046	0.6023	0.4266
12/21/98			0.3009	0.0321	0.5526	0.0778	0.4339	0.3195
12/28/98			0.2927	0.0338	0.5736	0.0859	0.4521	0.3284
01/04/99			0.3181	0.0381	0.6091	0.0873	0.4825	0.3495
01/12/99			0.2892	0.0364	0.5587	0.0846	0.4454	0.3243
01/19/99			0.4289	0.0441	0.8477	0.1159	0.6703	0.4699
01/26/99			0.3868	0.0420	0.7511	0.1085	0.6065	0.4295
02/02/99			0.4510	0.0477	0.8792	0.1218	0.7093	0.4996
02/09/99			0.4687	0.0498	0.9045	0.1323	0.7305	0.5057
02/16/99			0.4510	0.0488	0.8697	0.1259	0.7014	0.4899
02/23/99			0.4764	0.0507	0.9243	0.1315	0.7395	0.5189
03/02/99			0.5294	0.0543	0.9592	0.1317	0.6915	0.4940
03/09/99			0.5024	0.0515	0.9348	0.1298	0.6735	0.4801
03/16/99			0.5154	0.0538	0.9734	0.1341	0.6986	0.4970
03/23/99			0.5267	0.0543	0.9722	0.1328	0.7037	0.5020
03/30/99			0.5019	0.0515	0.9397	0.1313	0.6776	0.4844
04/06/99			0.5149	0.0539	0.8950	0.1240	0.6313	0.4507
04/13/99			0.5301	0.0546	0.9897	0.1361	0.7107	0.5061
04/20/99			0.4919	0.0523	0.9400	0.1304	0.6757	0.4825
04/27/99			0.4198	0.0461	0.8469	0.1161	0.5986	0.4298
05/04/99			0.4793	0.0503	0.9426	0.1307	0.6632	0.4759
05/11/99			0.4971	0.0520	0.9525	0.1306	0.6833	0.4865
05/18/99			0.4868	0.0515	0.9451	0.1295	0.6795	0.4840
05/25/99			0.4849	0.0515	0.9509	0.1307	0.6801	0.4875

Date	Time	Q_S	Cl	SO_4	Na	K	Mg	Ca
06/01/99			0.4611	0.0506	0.9355	0.1302	0.6753	0.4880
06/08/99			0.3269	0.0397	0.6544	0.0926	0.4549	0.3293
06/15/99			0.3240	0.0379	1.2926	0.1876	0.9136	0.6520
06/22/99			0.4525	0.0527	0.9957	0.1541	0.6996	0.5034
06/29/99			0.2996	0.0345	1.1129	0.2018	0.7309	0.5244
07/06/99			0.4594	0.0479	0.6268	0.0969	0.4468	0.3183
07/13/99			0.3811	0.0439	1.1452	0.1833	0.7850	0.5646
07/20/99			0.3671	0.0547	0.6378	0.0927	0.4584	0.3261
07/27/99			0.3017	0.0347	0.4235	0.1289	0.2468	0.1843
08/04/99			0.4193	0.0432	0.4835	0.0703	0.3325	0.2379
08/10/99			0.4038	0.0446	0.8684	0.1356	0.6051	0.4189
08/17/99			no data	no data	0.3919	0.0609	0.2394	0.1453
08/24/99			0.3624	0.0393	0.9540	0.1321	0.6684	0.4793
08/31/99			0.4807	0.0486	0.9929	0.1408	0.7013	0.5025
09/07/99			0.4949	0.0503	0.8787	0.1255	0.6383	0.4582
09/14/99			0.4918	0.0509	0.8979	0.1271	0.6386	0.4537
09/21/99			0.5000	0.0514	0.9475	0.1296	0.6855	0.4920
09/28/99			0.4673	0.0457	0.9334	0.1247	0.6561	0.4726
10/05/99			0.4551	0.0475	0.8811	0.1198	0.6311	0.4544
10/12/99			0.4720	0.0497	0.9011	0.1237	0.6504	0.4667
10/19/99			0.4372	0.0456	0.8650	0.1197	0.6113	0.4395
10/26/99			0.3253	0.0362	1.0112	0.1473	0.6946	0.4946
11/02/99			0.4500	0.0469	0.5025	0.0828	0.3477	0.2471
11/09/99			0.3918	0.0566	1.1423	0.5395	0.5256	0.5355
11/16/99			0.4089	0.0509	0.7679	0.1345	0.5175	0.3712
11/23/99			0.4115	0.0429	0.6701	0.1009	0.4738	0.3406
11/30/99			0.4001	0.0455	0.5993	0.1125	0.4049	0.2838
12/07/99			0.2715	0.0347	0.6163	0.0992	0.4150	0.3092
12/14/99			0.4416	0.0512	0.8087	0.1183	0.5772	0.4186
12/21/99			0.3980	0.0443	0.7348	0.1005	0.5232	0.3820
12/28/99			0.4207	0.0443	0.8231	0.1148	0.5864	0.4279
02/01/00			0.4124	0.0130	0.8322	0.1149	0.5927	0.4244
02/06/00			0.1730	0.0078	0.3212	0.0519	0.2192	0.1683
02/07/00			0.0887	0.0042	0.1178	0.0208	0.0650	0.0711
02/14/00			0.3459	0.0151	0.8697	0.1113	0.5952	0.4990
02/21/00	1100	12.00	0.0930	0.0059	0.2749	0.0407	0.1613	0.1343
02/28/00	1015	10.44	0.3792	0.0133	0.9324	0.0377	0.6518	0.5224
03/06/00	1145	9.71	0.4225	0.0144	0.9743	0.1528	0.6708	0.5037
03/16/00	1005	9.71	0.4614	0.0157	0.9494	0.1328	0.7095	0.5243
03/23/00	1025	9.01	0.4573	0.0157	0.9594	0.1333	0.7206	0.5338
03/30/00	1035	9.01	0.4638	0.0159	0.9745	0.1345	0.7344	0.5437
04/06/00	1000	8.35	0.4665	0.0160	0.9821	0.1356	0.7342	0.5383
04/13/00	1015	9.71	0.4599	0.0158	0.9459	0.1297	0.7104	0.5336
04/20/00	1100	9.01	0.4381	0.0154	0.9664	0.1350	0.7240	0.5507

Date	Time	Q_S	Cl	SO_4	Na	K	Mg	Ca
04/27/00	1056	9.01	0.4710	0.0164	0.9690	0.1323	0.7277	0.5497
05/04/00	1043	9.01	0.4248	0.0151	0.9771	0.1360	0.7541	0.5790
05/11/00	1108	9.71	0.4392	0.0166	0.9351	0.1326	0.7171	0.5488
05/18/00	1100	9.71	0.4582	0.0160	0.9568	0.1365	0.7365	0.5648
05/25/00	1057	9.36	0.4553	0.0165	0.9452	0.1307	0.7139	0.5457
06/01/00	1044	9.71	0.4366	0.0154	0.9442	0.1286	0.7123	0.5438
06/08/00	1106	11.21	0.3781	0.0138	0.8360	0.1157	0.6305	0.4853
06/15/00	1009	12.00	0.4495	0.0159	0.9193	0.1278	0.6916	0.5306
06/22/00	1046	12.00	0.3797	0.0132	0.7954	0.1091	0.5982	0.4614
06/29/00	1033	12.83	0.3827	0.0127	0.7739	0.1064	0.5796	0.4470
07/06/00	1042	12.83	0.3730	0.0124	0.7506	0.1039	0.5622	0.4346
07/13/00	941	11.60	0.4012	0.0135	0.8021	0.1140	0.6023	0.4639
07/20/00	1042	12.00	0.3629	0.0122	0.7992	0.1109	0.5973	0.4593
07/27/00	1014	13.69	0.3583	0.0121	0.6819	0.0950	0.5097	0.3950
08/03/00	1100	11.21	0.4064	0.0140	0.8321	0.1156	0.6218	0.4791
08/10/00	1003	12.41	0.3638	0.0122	0.7706	0.1065	0.5738	0.4461
08/17/00	1057	16.47	0.3662	0.0123	0.7340	0.1019	0.5491	0.4307
08/24/00	1015	13.69	0.3184	0.0112	0.7066	0.0980	0.5256	0.4092
08/31/00	1035	11.21	0.4008	0.0133	0.8217	0.1142	0.6109	0.4747
09/07/00	1015	10.44	0.4289	0.0141	0.8728	0.1215	0.6552	0.5057
09/14/00	1035	9.71	0.4494	0.0149	0.9222	0.1275	0.6804	0.5252
09/21/00	1043	9.71	0.4644	0.0164	0.9452	0.1309	0.7031	0.5429
09/28/00	1030	9.71	0.4561	0.0157	0.9361	0.1296	0.6945	0.5367
10/05/00	1000	9.71	0.4742	0.0163	0.9138	0.1279	0.6675	0.5138
10/12/00	1031	9.71	0.4499	0.0152	0.9308	0.1297	0.6969	0.5447
10/19/00	1042	10.44	0.1843	0.0091	0.3197	0.0536	0.2064	0.1705
10/26/00	1044	6.53	0.4480	0.0152	0.9249	0.1255	0.6889	0.5405
11/02/00	1005	12.83	0.3687	0.0131	0.7486	0.0976	0.5584	0.4407
11/09/00	1040	11.21	0.4091	0.0136	0.8339	0.1057	0.6094	0.4479
11/16/00	1016	10.44	0.4331	0.0142	0.9082	0.1264	0.6505	0.4833
11/23/00	1100	12.41	0.3817	0.0131	0.7746	0.0990	0.5663	0.4213
11/30/00	1030	10.82	0.4262	0.0141	0.8710	0.1116	0.6375	0.4778
12/07/00	1047	10.44	0.4327	0.0142	0.8998	0.1191	0.6537	0.4903
12/14/00	1109	10.44	0.4236	0.0143	0.8715	0.1086	0.6413	0.4848
12/21/00	1040	10.44	0.4413	0.0146	0.9075	0.1146	0.6674	0.5048
12/28/00	1023	10.44	0.4332	0.0143	0.8833	0.1129	0.6458	0.4900
01/04/01	1046	0.00	0.3642	0.0126	0.7383	0.0948	0.5436	0.4174
01/11/01	1105	11.21	0.4108	0.0139	0.8431	0.1090	0.6200	0.4747
01/18/01	1107	9.71	0.4447	0.0147	0.9108	0.1179	0.6715	0.5203
01/25/01	1046	14.58	0.3123	0.0116	0.6363	0.0871	0.4705	0.3652
02/01/01	1052	6.53	0.4354	0.0147	0.8809	0.1235	0.6636	0.4963
02/08/01	1042	9.71	0.4513	0.0153	0.8964	0.1262	0.6700	0.4970
02/15/01	1050	10.44	0.4377	0.0146	0.8805	0.1229	0.6588	0.4905
02/22/01	850	9.71	0.4588	0.0155	0.9194	0.1280	0.6897	0.5113

Date	Time	Q_S	Cl	SO_4	Na	K	Mg	Ca
03/01/01	1043	9.36	0.4687	0.0157	0.9372	0.1320	0.7031	0.5237
03/08/01	830	9.01	0.4724	0.0157	0.9408	0.1326	0.7085	0.5291
03/15/01	1102	9.01	0.4778	0.0159	0.9654	0.1359	0.7112	0.5647
03/22/01	900	9.01	0.4843	0.0163	0.9687	0.1374	0.7418	0.6219
03/29/01	1110	9.01	0.4743	0.0165	0.9521	0.1353	0.7239	0.5519
04/05/01	845	9.01	0.4874	0.0162	0.9758	0.1368	0.7434	0.5682
04/12/01	1046	9.71	0.4707	0.0159	0.9401	0.1347	0.7196	0.5544
04/19/01	853	9.71	0.4659	0.0165	0.9236	0.1290	0.7072	0.5434
04/26/01	1040	9.01	0.4774	0.0165	0.9609	0.1358	0.7340	0.5623
05/03/01	906	9.36	0.4666	0.0163	0.9421	0.1335	0.7209	0.5550
05/10/01	1116	9.01	0.4784	0.0162	0.1874	0.0345	0.1531	0.3314
05/17/01	907	9.01	0.4718	0.0162	0.9548	0.1336	0.7281	0.5454
05/24/01	1125	9.01	0.4784	0.0168	0.9700	0.1352	0.7390	0.5533
05/31/01	924	9.71	0.4684	0.0159	0.9473	0.1334	0.7287	0.5493
06/07/01	900	11.21	0.3603	0.0150	0.7226	0.1106	0.5420	0.4141
06/14/01	910	9.36	0.4630	0.0159	0.9388	0.1345	0.7051	0.5529
06/21/01	910	12.83	0.3986	0.0145	0.8016	0.1155	0.6077	0.4832
06/28/01	800	172.66	0.0829	0.0065	0.0734	0.0151	0.0172	0.0241
07/05/01	1410	13.69	0.3597	0.0122	0.7155	0.1033	0.5299	0.4198
07/12/01	830	13.69	0.3579	0.0123	0.7174	0.1014	0.5316	0.4182
07/19/01	935	12.83	0.7766	0.0261	0.7248	0.1034	0.5353	0.4256
07/26/01	815	11.21	0.4016	0.0135	0.8089	0.1158	0.5983	0.4724
08/02/01	857	10.44	0.4167	0.0142	0.8697	0.1244	0.6474	0.5115
08/09/01	740	10.44	0.1214	0.0042	0.8375	0.1200	0.6193	0.4892
08/16/01	830	13.69	0.3495	0.0124	0.6864	0.0967	0.5075	0.3784
08/23/01	842	10.44	0.4254	0.0144	0.8631	0.1230	0.6372	0.5057
08/30/01	903	10.44	0.4083	0.0139	0.8312	0.1192	0.6154	0.4895
09/06/01	835	10.44	0.4161	0.0140	0.8610	0.1208	0.6306	0.5002
09/13/01	839	9.71	0.4222	0.0145	0.9070	0.1300	0.6594	0.5228
09/20/01	845	10.44	0.4218	0.0143	0.8639	0.1219	0.6346	0.5111
09/27/01	840	9.71	0.1305	0.0041	0.4547	0.0660	0.3496	0.3451
10/04/01	820	12.41	0.0766	0.0028	0.1170	0.0163	0.1031	0.1181
10/11/01	834	10.44	0.4126	0.0139	0.8367	0.1174	0.6135	0.4850
10/18/01	840	10.44	0.4135	0.0142	0.8383	0.1193	0.6107	0.4796
10/25/01	900	10.44	0.1356	0.0046	0.8718	0.1224	0.6299	0.4942
11/01/01	833	9.71	0.4447	0.0157	0.9039	0.1295	0.6531	0.5124
11/08/01	850	14.58	0.3295	0.0128	0.6574	0.0935	0.4758	0.3822
11/15/01	855	15.51	0.3385	0.0115	0.6689	0.0901	0.4882	0.3892
11/22/01	855	20.68	0.2404	0.0088	0.4499	0.0620	0.3125	0.2399
11/29/01	850	12.83	0.1517	0.0045	0.7324	0.1026	0.5335	0.4258
12/06/01	830	no data	0.0551	0.0038	0.0421	0.0155	0.0242	0.0261
12/13/01	1005	67.88	0.0443	0.0000	0.1482	0.0209	0.0961	0.0780
12/20/01	908	14.58	0.2550	0.0088	0.6161	0.0864	0.4416	0.3479
12/27/01	900	20.68	0.2514	0.0087	0.6109	0.0906	0.4403	0.3521

Date	Time	Q_S	Cl	SO_4	Na	K	Mg	Ca
01/03/02	1117	11.21	0.3297	0.0105	0.8056	0.1140	0.5828	0.4630
01/10/02	852	213.37	0.2176	0.0070	0.5382	0.0746	0.3704	0.2935
01/17/02	1115	10.44	0.3395	0.0106	0.8391	0.1188	0.6077	0.4840
01/24/02	930	10.07	0.3430	0.0114	0.8747	0.1237	0.6369	0.5083
01/31/02	1115	11.21	0.3212	0.0106	0.8263	0.1174	0.5994	0.4793
02/07/02	930	10.44	0.3450	0.0112	0.8695	0.1250	0.6342	0.5081
02/14/02	1105	9.71	0.3681	0.0114	0.9114	0.1291	0.6789	0.5441
02/21/02	840	9.71	0.4702	0.0187	0.9345	0.1323	0.6931	0.5539
02/28/02	1110	9.71	0.4618	0.0192	0.9385	0.1326	0.6988	0.5630
03/07/02	900	9.01	0.4770	0.0182	0.9539	0.1377	0.7073	0.5669
03/14/02	1117	9.01	0.4757	0.0187	0.9547	0.1281	0.6962	0.5503
03/24/02	920	9.71	0.4729	0.0192	0.9459	0.1344	0.6896	0.5465
03/28/02	1100	9.01	0.4828	0.0195	0.9603	0.1360	0.6979	0.5542
04/04/02	845	9.01	0.4665	0.0160	0.9518	0.1319	0.6996	0.5182
04/11/02	1110	9.01	0.4955	0.0192	0.9553	0.1313	0.7010	0.5154
04/18/02	930	9.01	0.4864	0.0199	0.9627	0.1317	0.7062	0.5220
04/25/02	1040	9.36	0.4768	0.0196	0.9197	0.1252	0.6753	0.4998
05/02/02	905	9.01	0.4933	0.0202	0.9566	0.1341	0.7016	0.5214
05/09/02	1100	140.52	0.1398	0.0088	0.1873	0.0290	0.1049	0.0885
05/16/02	938	15.51	0.3414	0.0145	0.6227	0.0839	0.4477	0.3336
05/23/02	1042	12.41	0.4784	0.0168	0.7548	0.1042	0.5487	0.4065
05/30/02	855	11.21	0.4684	0.0159	0.8224	0.1144	0.6026	0.4484
06/06/02	1110	12.00	0.3603	0.0150	0.8356	0.1234	0.0025	0.4195
06/13/02	900	12.00	0.4630	0.0159	0.8605	0.1134	0.5616	0.3597
06/20/02	1035	10.82	0.3986	0.0145	0.8856	0.1191	0.6063	0.4188
06/27/02	1500	14.13	0.0829	0.0065	0.4521	0.0639	0.3066	0.2337
07/04/02	817	14.58	0.3597	0.0122	0.6496	0.0838	0.4599	0.3564
07/11/02	850	16.47	0.3579	0.0123	0.7174	0.1014	0.5316	0.4182
07/18/02	1045	12.83	0.3616	0.0124	0.7382	0.1026	0.5249	0.4084
07/25/02	no data	no data	0.3718	0.0129	0.7627	0.1032	0.5413	0.4205
08/01/02	1055	12.83	0.3521	0.0124	0.7184	0.0956	0.5109	0.3911
08/08/02	915	12.83	0.3612	0.0119	0.7389	0.1001	0.5267	0.4108
08/15/02	1135	98.83	0.1480	0.0049	0.2326	0.0343	0.1356	0.1152
08/22/02	823	162.79	0.1299	0.0061	0.1983	0.0339	0.1183	0.0963
08/29/02	1026	15.99	0.3058	0.0107	0.6128	0.0807	0.4277	0.3287
09/05/02	no data	no data	0.3655	0.0127	0.7534	0.1024	0.5361	0.4187
09/12/02	1055	10.44	0.4076	0.0141	0.8462	0.1144	0.6029	0.4666
09/19/02	no data	no data	0.3976	0.0136	0.8169	0.1096	0.5849	0.4576
09/26/02	1035	12.00	0.3820	0.0129	0.7773	0.1056	0.5518	0.4342
10/03/02	845	10.44	0.4124	0.0142	0.8527	0.1159	0.6073	0.4742
10/10/02	912	11.21	0.4133	0.0137	0.8507	0.1170	0.6061	0.4695
10/17/02	923	10.44	0.4269	0.0144	0.8834	0.1233	0.6315	0.4932
10/24/02	925	10.82	0.4242	0.0143	0.8796	0.1216	0.6296	0.4938
10/31/02	855	10.07	0.4211	0.0145	0.8791	0.1186	0.6276	0.4917

Date	Time	Q_S	Cl	SO_4	Na	K	Mg	Ca
11/07/02	920	9.71	0.4402	0.0152	0.9119	0.1238	0.6498	0.5044
11/14/02	917	9.71	0.4357	0.0148	0.8903	0.1187	0.6386	0.4994
11/21/02	900	12.00	0.3828	0.0133	0.7917	0.1028	0.5565	0.4336
11/28/02	910	16.47	0.3357	0.0121	0.6642	0.0918	0.4657	0.3599

Appendix 2. Chemical analyses of stream samples collected at the Taconazo weir.

Q_S (in m3/min) represents the manual stage reading at the time of the sample collection (note: no readings were available from 9/8/98 through 2/14/00). All concentrations are in mM.

Date	Time	Q_S	Cl	SO_4	Na	K	Mg	Ca
09/08/98			0.0728	0.0000	0.0695	0.0150	0.0223	0.0327
09/16/98			0.0752	0.0088	0.0684	0.0155	0.0190	0.0305
09/22/98			0.0727	0.0000	0.0718	0.0182	0.0250	0.0333
09/30/98			0.0771	0.0000	0.0699	0.0181	0.0202	0.0314
10/06/98			0.0857	0.0106	0.0741	0.0201	0.0222	0.0325
10/13/98			0.0723	0.0113	0.0579	0.0137	0.0161	0.0262
10/20/98			0.0736	0.0000	0.1108	0.0200	0.0214	0.0313
10/27/98			0.0746	0.0000	0.0622	0.0141	0.0164	0.0262
11/03/98			0.0988	0.0179	0.0624	0.0138	0.0178	0.0278
11/10/98			0.0737	0.0096	0.0614	0.0139	0.0160	0.0251
11/18/98			0.0769	0.0000	0.0627	0.0143	0.0180	0.0267
11/24/98			0.0746	0.0095	0.0625	0.0138	0.0175	0.0267
12/01/98			0.0729	0.0080	0.0672	0.0138	0.0202	0.0290
12/08/98			0.0757	0.0000	0.0594	0.0129	0.0167	0.0259
12/14/98			0.0740	0.0090	0.0594	0.0133	0.0162	0.0254
12/21/98			0.0751	0.0097	0.0571	0.0122	0.0154	0.0245
12/28/98			0.0741	0.0107	0.0555	0.0115	0.0163	0.0251
01/04/99			0.0790	0.0075	0.0579	0.0118	0.0160	0.0242
01/12/99			0.0730	0.0088	0.1006	0.0158	0.0276	0.0376
01/19/99			0.0759	0.0000	0.0634	0.0131	0.0181	0.0270
01/26/99			0.0917	0.0174	0.0662	0.0158	0.0180	0.0274
02/02/99			0.0776	0.0000	0.0666	0.0151	0.0204	0.0293
02/09/99			0.0999	0.0169	0.0692	0.0161	0.0208	0.0305
02/16/99			0.0749	0.0000	0.0716	0.0177	0.0185	0.0284
02/23/99			0.0818	0.0080	0.1004	0.0396	0.0203	0.0307
03/02/99			0.0748	0.0000	0.0607	0.0120	0.0133	0.0139
03/09/99			0.0825	0.0000	no data	no data	no data	no data
03/16/99			0.0749	0.0000	0.0789	0.0212	0.0173	0.0173
03/23/99			0.0760	0.0000	0.0821	0.0184	0.0187	0.0202
03/30/99			0.0825	0.0000	0.0852	0.0211	0.0174	0.0174
04/06/99			0.0769	0.0000	0.0845	0.0167	0.0224	0.0219
04/13/99			0.0800	0.0104	0.0876	0.0200	0.0205	0.0204
04/20/99			0.0809	0.0114	0.0755	0.0182	0.0150	0.0163
04/27/99			0.0729	0.0116	0.0628	0.0117	0.0136	0.0150
05/04/99			0.0762	0.0101	0.0919	0.0163	0.0175	0.0190
05/11/99			0.0833	0.0093	0.0602	0.0120	0.0121	0.0116
05/18/99			0.0766	0.0094	0.0717	0.0169	0.0139	0.0136
05/25/99			0.0738	0.0098	0.0719	0.0152	0.0153	0.0163

Date	Time	Q_S	Cl	SO_4	Na	K	Mg	Ca
06/01/99			0.0712	0.0091	0.0676	0.0125	0.0151	0.0193
06/08/99			0.0654	0.0097	0.0482	0.0097	0.0100	0.0104
06/15/99			0.0704	0.0077	0.0637	0.0123	0.0104	0.0098
06/22/99			0.0692	0.0074	0.0476	0.0118	0.0078	0.0105
06/29/99			0.0694	0.0116	0.1643	0.0603	0.0158	0.0142
07/06/99			0.0721	0.0079	0.1269	0.0612	0.0164	0.0164
07/13/99			0.0767	0.0126	0.1679	0.0713	0.0202	0.0256
07/20/99			0.0710	0.0109	0.0718	0.0148	0.0113	0.0111
07/27/99			0.0686	0.0100	0.1188	0.0684	0.0137	0.0152
08/04/99			0.0715	0.0100	0.1270	0.0575	0.0129	0.0147
08/10/99			0.0748	0.0112	0.0490	0.0118	0.0088	0.0094
08/17/99			no data	no data	0.0795	0.0146	0.0143	0.0128
08/24/99			0.0605	0.0081	0.0710	0.0148	0.0116	0.0120
08/31/99			0.0715	0.0079	0.0735	0.0166	0.0128	0.0147
09/07/99			0.0682	0.0088	0.0629	0.0173	0.0156	0.0183
09/14/99			0.0698	0.0081	0.0702	0.0170	0.0149	0.0167
09/21/99			0.0699	0.0081	0.0794	0.0173	0.0162	0.0166
09/28/99			0.0689	0.0073	0.0674	0.0167	0.0125	0.0140
10/05/99			0.0710	0.0084	0.0620	0.0102	0.0119	0.0139
10/12/99			0.0686	0.0075	0.0614	0.0118	0.0124	0.0132
10/19/99			0.0699	0.0078	0.0641	0.0119	0.0120	0.0131
10/26/99			0.0728	0.0119	0.0618	0.0156	0.0100	0.0095
11/02/99			0.0760	0.0090	0.0595	0.0112	0.0109	0.0087
11/09/99			no data	no data	0.0549	0.0215	0.0088	0.0144
11/16/99			0.0764	0.0095	0.0518	0.0146	0.0098	0.0099
11/23/99			0.0605	0.0114	0.0682	0.0163	0.0100	0.0101
11/30/99			0.0751	0.0123	0.0519	0.0129	0.0092	0.0096
12/07/99			0.0714	0.0087	0.0974	0.0206	0.0227	0.0400
12/14/99			0.0720	0.0091	0.0934	0.0308	0.0140	0.0110
12/21/99			no data	no data	0.0624	0.0106	0.0094	0.0097
12/28/99			0.0777	0.0099	0.0611	0.0099	0.0114	0.0141
02/01/00			0.0633	0.0025	0.0622	0.0105	0.0093	0.0121
02/06/00			0.0472	0.0046	0.0483	0.0093	0.0098	0.0129
02/07/00			0.0597	0.0041	0.0519	0.0093	0.0096	0.0118
02/14/00			0.0576	0.0024	0.0641	0.0083	0.0109	0.0136
02/21/00	915	2.08	0.0541	0.0046	0.0718	0.0097	0.0120	0.0562
02/28/00	840	1.12	0.0464	0.0021	0.0636	0.0090	0.0132	0.0148
03/06/00	834	1.12	0.0581	0.0024	0.0704	0.0109	0.0126	0.0159
03/16/00	758	0.60	0.0591	0.0023	0.0684	0.0114	0.0148	0.0165
03/23/00	822	0.41	0.0554	0.0023	0.0715	0.0115	0.0150	0.0171
03/30/00	810	0.33	0.0564	0.0024	0.0731	0.0125	0.0149	0.0186
04/06/00	810	0.20	0.0564	0.0025	0.0763	0.0137	0.0163	0.0201
04/13/00	812	0.50	0.0577	0.0028	0.0702	0.0126	0.0148	0.0169
04/20/00	900	0.37	0.0596	0.0025	0.0742	0.0131	0.0157	0.0188

Date	Time	Q_S	Cl	SO_4	Na	K	Mg	Ca
04/27/00	855	0.41	0.0672	0.0028	0.0800	0.0160	0.0161	0.0191
05/04/00	840	0.26	0.0644	0.0026	0.0758	0.0140	0.0175	0.0212
05/11/00	847	0.84	0.0660	0.0034	0.0769	0.0196	0.0177	0.0199
05/18/00	857	0.33	0.0618	0.0029	0.0859	0.0184	0.0179	0.0220
05/25/00	857	0.41	0.0608	0.0035	0.0677	0.0153	0.0136	0.0154
06/01/00	842	0.60	0.0553	0.0026	0.0712	0.0142	0.0157	0.0171
06/08/00	901	1.12	0.0569	0.0030	0.0605	0.0124	0.0136	0.0149
06/15/00	823	0.60	0.0577	0.0026	0.0582	0.0115	0.0152	0.0168
06/22/00	844	1.86	0.0557	0.0027	0.0515	0.0097	0.0126	0.0129
06/29/00	850	2.31	0.0600	0.0026	0.0522	0.0087	0.0117	0.0120
07/06/00	840	2.19	0.0573	0.0025	0.0609	0.0084	0.0112	0.0115
07/13/00	815	1.86	0.0603	0.0024	0.0542	0.0090	0.0121	0.0125
07/20/00	845	1.86	0.0588	0.0024	0.0513	0.0082	0.0118	0.0116
07/27/00	835	2.82	0.0612	0.0025	0.0570	0.0074	0.0100	0.0077
08/03/00	905	1.46	0.0553	0.0023	0.0562	0.0081	0.0116	0.0117
08/10/00	827	1.86	0.0552	0.0025	0.0591	0.0086	0.0110	0.0116
08/17/00	845	1.65	0.0587	0.0025	0.0627	0.0079	0.0115	0.0118
08/24/00	830	2.82	0.0567	0.0026	0.0595	0.0076	0.0116	0.0119
08/31/00	850	1.75	0.0589	0.0024	0.0529	0.0079	0.0118	0.0116
09/07/00	835	1.12	0.0569	0.0024	0.0545	0.0087	0.0132	0.0135
09/14/00	845	0.84	0.0589	0.0024	0.0643	0.0095	0.0147	0.0157
09/21/00	905	0.60	0.0578	0.0025	0.0661	0.0108	0.0142	0.0163
09/28/00	840	0.66	0.0585	0.0028	0.0662	0.0116	0.0116	0.0133
10/05/00	825	0.60	0.0580	0.0025	0.0672	0.0112	0.0136	0.0153
10/12/00	843	0.84	0.0590	0.0025	0.0626	0.0105	0.0140	0.0156
10/19/00	855	1.46	0.0551	0.0030	0.0595	0.0135	0.0137	0.0170
10/26/00	855	0.90	0.0580	0.0025	0.0634	0.0100	0.0133	0.0169
11/02/00	822	2.08	0.0552	0.0027	0.0581	0.0107	0.0130	0.0172
11/09/00	850	1.65	0.0565	0.0025	0.0595	0.0082	0.0130	0.0154
11/16/00	840	1.12	0.0573	0.0024	0.0614	0.0100	0.0115	0.0155
11/23/00	903	2.19	0.0601	0.0026	0.0621	0.0119	0.0127	0.0153
11/30/00	845	1.29	0.0609	0.0026	0.0654	0.0116	0.0136	0.0167
12/07/00	838	0.97	0.0568	0.0025	0.0634	0.0118	0.0127	0.0155
12/14/00	853	1.12	0.0616	0.0026	0.0624	0.0101	0.0122	0.0157
12/21/00	840	0.84	0.0590	0.0024	0.0673	0.0104	0.0129	0.0152
12/28/00	833	1.12	0.0557	0.0025	0.0604	0.0094	0.0126	0.0153
01/04/01	835	1.12	0.0698	0.0028	0.0643	0.0100	0.0130	0.0154
01/11/01	842	1.46	0.0541	0.0024	0.0597	0.0089	0.0122	0.0156
01/18/01	845	0.90	0.0580	0.0025	0.0664	0.0093	0.0130	0.0163
01/25/01	855	3.10	0.0515	0.0027	0.0523	0.0108	0.0117	0.0137
02/01/01	840	0.97	0.0591	0.0021	0.0598	0.0091	0.0135	0.0147
02/08/01	853	0.71	0.0607	0.0022	0.0614	0.0110	0.0145	0.0156
02/15/01	836	0.84	0.0670	0.0022	0.0665	0.0110	0.0149	0.0157
02/22/01	826	0.60	0.0596	0.0021	0.0612	0.0104	0.0147	0.0158

Date	Time	Q_S	Cl	SO_4	Na	K	Mg	Ca
03/01/01	840	0.50	0.0568	0.0021	0.0624	0.0121	0.0149	0.0168
03/08/01	808	0.37	0.0703	0.0024	0.0688	0.0138	0.0166	0.0176
03/15/01	902	0.26	0.0593	0.0026	0.0724	0.0116	0.0150	0.0134
03/22/01	836	0.37	0.0620	0.0023	0.0710	0.0147	0.0175	0.0195
03/29/01	858	0.26	0.0668	0.0027	0.0710	0.0140	0.0174	0.0189
04/05/01	815	0.20	0.0596	0.0021	0.0734	0.0152	0.0189	0.0214
04/12/01	848	0.41	0.0690	0.0028	0.0769	0.0178	0.0197	0.0213
04/19/01	832	0.55	0.0659	0.0026	0.0687	0.0128	0.0172	0.0188
04/26/01	845	0.29	0.0603	0.0020	0.0749	0.0142	0.0186	0.0216
05/03/01	843	0.41	0.0630	0.0021	0.0734	0.0148	0.0182	0.0208
05/10/01	918	0.26	0.0290	0.0016	0.0682	0.0136	0.0182	0.0206
05/17/01	838	0.26	0.0597	0.0024	0.0669	0.0138	0.0153	0.0176
05/24/01	923	0.20	0.0586	0.0022	0.0695	0.0141	0.0174	0.0202
05/31/01	924	0.26	0.0606	0.0022	0.0711	0.0154	0.0188	0.0218
06/07/01	900	2.31	0.0554	0.0031	0.0579	0.0187	0.0145	0.0150
06/14/01	910	0.45	0.0646	0.0022	0.0732	0.0135	0.0168	0.0176
06/21/01	910	1.29	0.0686	0.0025	0.0647	0.0125	0.0155	0.0153
06/28/01	800	196.60	0.0742	0.0065	0.0995	0.0197	0.0516	0.0522
07/05/01	1410	2.82	0.0632	0.0022	0.0565	0.0075	0.0119	0.0111
07/12/01	830	2.31	0.0577	0.0019	0.0562	0.0072	0.0118	0.0116
07/19/01	935	2.19	0.0595	0.0021	0.0565	0.0075	0.0118	0.0117
07/26/01	815	1.46	0.0590	0.0018	0.0595	0.0077	0.0125	0.0121
08/02/01	857	0.97	0.0578	0.0018	0.0604	0.0085	0.0131	0.0129
08/09/01	740	1.12	0.0595	0.0019	0.0599	0.0092	0.0133	0.0135
08/16/01	830	2.56	0.0119	0.0000	0.0531	0.0092	0.0122	0.0127
08/23/01	842	1.12	0.0586	0.0018	0.0615	0.0085	0.0136	0.0143
08/30/01	903	1.29	0.0561	0.0018	0.0571	0.0081	0.0125	0.0120
09/06/01	835	1.12	0.0578	0.0018	0.0647	0.0087	0.0129	0.0130
09/13/01	839	0.84	0.0548	0.0017	0.0641	0.0094	0.0132	0.0142
09/20/01	845	0.84	0.0548	0.0021	0.0604	0.0092	0.0123	0.0124
09/27/01	840	0.71	0.0592	0.0019	0.0063	0.0016	0.0000	0.0012
10/04/01	820	1.86	0.0549	0.0021	0.0036	0.0012	0.0024	0.0005
10/11/01	834	1.46	0.0573	0.0018	0.0585	0.0080	0.0109	0.0092
10/18/01	840	1.37	0.0560	0.0018	0.0577	0.0080	0.0102	0.0085
10/25/01	900	1.12	0.0563	0.0018	0.0601	0.0090	0.0106	0.0091
11/01/01	833	0.84	0.0572	0.0018	0.1948	0.0772	0.0128	0.0113
11/08/01	850	3.10	0.0588	0.0028	0.0521	0.0088	0.0094	0.0070
11/15/01	855	3.10	0.0581	0.0022	0.0563	0.0072	0.0095	0.0082
11/22/01	855	8.02	0.0455	0.0025	0.0513	0.0069	0.0102	0.0078
11/29/01	850	2.31	0.0534	0.0018	0.0555	0.0062	0.0098	0.0068
12/06/01	no data	no data	0.0414	0.0025	0.0540	0.0155	0.0157	0.0127
12/13/01	1005	14.54	0.0285	0.0022	0.0371	0.0069	0.0075	0.0053
12/20/01	908	3.39	0.0422	0.0017	0.0474	0.0052	0.0079	0.0050
12/27/01	900	6.36	0.0378	0.0024	0.0520	0.0087	0.0104	0.0072

Date	Time	Q_S	Cl	SO_4	Na	K	Mg	Ca
01/03/02	910	1.75	0.0416	0.0000	0.0578	0.0078	0.0102	0.0077
01/10/02	830	3.71	0.0469	0.0019	0.0592	0.0067	0.0104	0.0083
01/17/02	900	1.29	0.0404	0.0017	0.0589	0.0072	0.0114	0.0084
01/24/02	905	0.84	0.0416	0.0018	0.0590	0.0092	0.0115	0.0099
01/31/02	910	1.12	0.0545	0.0016	0.0671	0.0094	0.0122	0.0097
02/07/02	900	1.05	0.0473	0.0017	0.0633	0.0082	0.0121	0.0090
02/14/02	905	0.71	0.0417	0.0016	0.0639	0.0083	0.0125	0.0094
02/21/02	820	0.55	0.0666	0.0000	0.0654	0.0095	0.0133	0.0103
02/28/02	907	0.41	0.0698	0.0000	0.0685	0.0101	0.0136	0.0110
03/07/02	838	0.33	0.0883	0.0000	0.0739	0.0110	0.0147	0.0129
03/14/02	910	0.26	0.0843	0.0000	0.0646	0.0120	0.0148	0.0136
03/24/02	905	0.60	0.0859	0.0067	0.0690	0.0113	0.0148	0.0126
03/28/02	853	0.26	0.0877	0.0065	0.0712	0.0113	0.0155	0.0137
04/04/02	824	0.26	no data	no data	0.0712	0.0113	0.0155	0.0137
04/11/02	910	0.20	0.0843	0.0000	0.0717	0.0171	0.0174	0.0228
04/18/02	900	0.15	0.0843	0.0066	0.0726	0.0171	0.0183	0.0227
04/25/02	847	0.37	0.1024	0.0077	0.0762	0.0153	0.0173	0.0224
05/02/02	843	0.15	0.0917	0.0000	0.0752	0.0162	0.0172	0.0203
05/09/02	840	4.74	0.1029	0.0071	0.0774	0.0166	0.0176	0.0220
05/16/02	917	3.71	0.0881	0.0066	0.0605	0.0186	0.0172	0.0184
05/23/02	833	2.08	0.0586	0.0022	0.0575	0.0101	0.0112	0.0137
05/30/02	840	6.36	0.0606	0.0022	0.0585	0.0103	0.0121	0.0138
06/06/02	835	1.86	0.0554	0.0031	0.0602	0.0111	0.0121	0.0144
06/13/02	838	4.74	0.0646	0.0022	0.0039	0.0079	0.0037	0.0053
06/20/02	830	1.29	0.0686	0.0025	0.0763	0.0067	0.0027	0.0039
06/27/02	1517	2.69	0.0742	0.0065	0.0603	0.0100	0.0074	0.0095
07/04/02	845	3.39	0.0632	0.0022	0.0518	0.0099	0.0099	0.0121
07/11/02	830	3.71	0.0577	0.0019	0.0544	0.0098	0.0103	0.0129
07/18/02	845	2.31	0.0571	0.0029	0.0562	0.0072	0.0118	0.0116
07/25/02	no data	no data	0.0552	0.0000	0.0586	0.0093	0.0109	0.0118
08/01/02	845	2.31	0.0493	0.0033	0.0594	0.0092	0.0102	0.0121
08/08/02	855	2.19	0.0565	0.0029	0.0521	0.0113	0.0110	0.0128
08/15/02	927	4.38	0.0906	0.0033	0.0580	0.0090	0.0091	0.0128
08/22/02	803	25.78	0.0503	0.0031	0.0741	0.0120	0.0137	0.0155
08/29/02	830	4.38	0.0543	0.0030	0.0535	0.0095	0.0103	0.0118
09/05/02	no data	no data	0.0567	0.0028	0.0555	0.0092	0.0085	0.0106
09/12/02	908	1.12	0.0566	0.0000	0.0578	0.0092	0.0102	0.0123
09/19/02	no data	no data	0.0549	0.0030	0.0603	0.0092	0.0114	0.0140
09/26/02	845	1.86	0.0496	0.0032	0.0569	0.0097	0.0101	0.0115
10/03/02	817	1.29	0.0527	0.0000	0.0550	0.0098	0.0087	0.0119
10/10/02	842	1.12	0.0536	0.0030	0.0610	0.0100	0.0111	0.0130
10/17/02	850	0.84	0.0571	0.0028	0.0803	0.0120	0.0125	0.0153
10/24/02	857	0.97	0.0574	0.0029	0.0630	0.0121	0.0116	0.0132
10/31/02	830	0.84	0.0541	0.0030	0.0720	0.0129	0.0118	0.0145

Date	Time	Q_S	Cl	SO_4	Na	K	Mg	Ca
11/07/02	847	0.60	0.0551	0.0000	0.0603	0.0114	0.0118	0.0144
11/14/02	855	2.69	0.0550	0.0000	0.0645	0.0119	0.0126	0.0150
11/21/02	833	1.86	0.0098	0.0000	0.0616	0.0115	0.0126	0.0147
11/28/02	835	2.82	0.0674	0.0033	0.0581	0.0104	0.0102	0.0131

Appendix 3. Chemical analyses of water samples collected at Gaucimo Spring (G.S.), Arbo4, Taco8, and wells 1 through 7.

All concentrations are in mM.

Date	Location	Cl	SO_4	Na	K	Mg	Ca
01/14/98	G.S.	0.8127	0.1272	1.9342	0.2371	1.7018	0.8790
02/03/98	G.S.	0.8198	0.1282	1.9865	0.2440	1.7523	0.9267
03/09/98	G.S.	0.9209	0.1291	1.9392	0.2412	1.7007	0.8859
04/03/98	G.S.	0.8797	0.1240	1.9373	0.2408	1.7093	0.8980
05/06/98	G.S.	0.8720	0.1235	1.9445	0.2388	1.7140	0.8902
06/03/98	G.S.	0.8775	0.1294	1.9762	0.1745	1.7314	0.9076
07/01/98	G.S.	0.9170	0.1147	1.7620	0.2421	1.5890	0.7617
08/14/98	G.S.	0.9388	0.1149	1.8151	0.2457	1.6390	0.7874
09/03/98	G.S.	0.9153	0.1145	1.8208	0.2364	1.6321	0.7799
10/06/98	G.S.	0.9396	0.1154	1.6122	0.2364	1.4130	0.6679
11/04/98	G.S.	0.7499	0.0941	1.5493	0.2402	1.2899	0.5721
12/02/98	G.S.	0.9362	0.1184	1.9810	0.2468	1.7790	0.8501
01/12/99	G.S.	0.9453	0.1319	1.9880	0.2122	1.7870	0.8531
02/02/99	G.S.	0.9384	0.1335	1.5159	0.2353	1.2870	0.5579
03/03/99	G.S.	0.9079	0.1359	no data	no data	no data	no data
04/07/99	G.S.	0.9292	0.1349	no data	no data	no data	no data
05/05/99	G.S.	0.9343	0.1336	no data	no data	no data	no data
06/03/99	G.S.	0.9078	0.1311	no data	no data	no data	no data
07/02/99	G.S.	0.9239	0.1331	no data	no data	no data	no data
08/05/99	G.S.	0.9328	0.1314	no data	no data	no data	no data
09/02/99	G.S.	0.9513	0.1356	no data	no data	no data	no data
10/06/99	G.S.	0.9168	0.1366	no data	no data	no data	no data
11/03/99	G.S.	0.9293	0.1337	no data	no data	no data	no data
12/02/99	G.S.	0.9518	0.1352	no data	no data	no data	no data
02/22/00	G.S.	0.9026	0.0444	2.0101	0.2482	1.7137	0.9105
02/29/00	G.S.	0.8537	0.0416	2.0019	0.2462	1.7054	0.8788
03/08/00	G.S.	0.7914	0.0344	2.0099	0.2440	1.7185	0.8926
03/17/00	G.S.	0.9140	0.0424	1.9718	0.2399	1.6931	0.8752
03/24/00	G.S.	0.9317	0.0434	1.9652	0.2385	1.6789	0.8643
03/31/00	G.S.	0.9308	0.0463	1.9375	0.2392	1.6518	0.8461
04/07/00	G.S.	0.9230	0.0463	0.9354	0.1146	0.8011	0.4212
04/14/00	G.S.	0.8766	0.0409	1.9647	0.2451	1.6774	0.8784
04/28/00	G.S.	0.8887	0.0408	1.9483	0.2436	1.7140	0.9140
05/05/00	G.S.	0.9233	0.0415	1.9436	0.2387	1.7297	0.9296
05/12/00	G.S.	0.8658	0.0404	no data	no data	no data	no data
05/19/00	G.S.	no data	no data	1.9479	0.2431	1.7118	0.9161
06/02/00	G.S.	0.8857	0.0413	1.9371	0.2415	1.6665	0.8833
06/09/00	G.S.	0.9161	0.0431	1.9676	0.2418	1.6887	0.8968
06/16/00	G.S.	0.9101	0.0416	2.0219	0.2504	1.7310	0.9139

Date	Location	Cl	SO_4	Na	K	Mg	Ca
06/18/00	G.S.	0.0785	0.0061	0.1553	0.0279	0.0917	0.0561
06/18/00	G.S.	0.9214	0.0427	1.9393	0.2420	1.6196	0.8488
06/18/00	G.S.	0.9194	0.0418	1.9407	0.2447	1.6155	0.8487
06/23/00	G.S.	0.9180	0.0424	1.9493	0.2388	1.6735	0.8905
06/23/00	G.S.	0.8529	0.0392	1.9216	0.2406	1.6559	0.8874
06/30/00	G.S.	0.9188	0.0419	1.9442	0.2398	1.6698	0.8906
06/30/00	G.S.	0.9182	0.0419	1.9360	0.2445	1.6616	0.8898
07/07/00	G.S.	0.9187	0.0430	1.9559	0.2471	1.6756	0.8953
07/07/00	G.S.	0.8935	0.0410	1.9539	0.2462	1.6768	0.8982
07/14/00	G.S.	0.8746	0.0411	1.8828	0.2327	1.6193	0.8729
07/14/00	G.S.	0.8360	0.0390	1.8866	0.2371	1.6135	0.8676
07/21/00	G.S.	0.9084	0.0436	1.9366	0.2409	1.6517	0.8811
07/21/00	G.S.	0.9136	0.0423	1.9396	0.2430	1.6577	0.8865
07/28/00	G.S.	0.9238	0.0424	no data	no data	no data	no data
08/04/00	G.S.	0.9130	0.0438	1.9368	0.2336	1.6616	0.8920
08/11/00	G.S.	0.9169	0.0434	1.9393	0.2341	1.6605	0.8929
08/18/00	G.S.	0.9147	0.0431	1.9298	0.2327	1.6531	0.8930
08/25/00	G.S.	0.9160	0.0425	1.9446	0.2356	1.6527	0.8906
09/01/00	G.S.	0.9203	0.0431	1.9107	0.2296	1.6327	0.8762
09/08/00	G.S.	0.9208	0.0418	1.9338	0.2435	1.6553	0.8906
09/15/00	G.S.	0.9167	0.0432	1.9580	0.2458	1.6633	0.8996
09/22/00	G.S.	0.9192	0.0434	1.9501	0.2410	1.6608	0.8981
10/06/00	G.S.	0.9254	0.0428	1.9571	0.2427	1.6680	0.9053
10/06/00	G.S.	0.9209	0.0432	1.9558	0.2435	1.6666	0.9054
10/13/00	G.S.	0.9272	0.0412	1.9602	0.2501	1.6799	0.9191
10/20/00	G.S.	0.9148	0.0420	1.9565	0.2426	1.6726	0.9097
10/27/00	G.S.	0.9217	0.0417	1.9619	0.2477	1.6561	0.8418
11/03/00	G.S.	0.8964	0.0406	1.9494	0.2420	1.6334	0.8151
11/10/00	G.S.	0.9134	0.0411	1.9573	0.2452	1.6386	0.8401
11/17/00	G.S.	0.9286	0.0416	1.9621	0.2435	1.6480	0.8491
11/24/00	G.S.	0.9072	0.0420	1.9419	0.2179	1.6420	0.8553
12/01/00	G.S.	0.9048	0.0401	1.9618	0.2240	1.6475	0.8567
12/08/00	G.S.	0.9191	0.0406	1.9579	0.2409	1.6396	0.8637
12/15/00	G.S.	0.9231	0.0402	1.9452	0.2183	1.6352	0.8649
12/28/00	G.S.	0.9196	0.0411	1.9521	0.2259	1.6430	0.8766
12/29/00	G.S.	0.9184	0.0421	1.9552	0.2239	1.6441	0.8674
01/05/01	G.S.	0.9179	0.0400	1.9574	0.2239	1.6496	0.8671
01/12/01	G.S.	0.9220	0.0398	1.9511	0.2229	1.6398	0.8630
01/19/01	G.S.	1.1521	0.0453	1.9517	0.2259	1.6488	0.8634
01/26/01	G.S.	0.9214	0.0400	1.9563	0.2266	1.6610	0.8890
02/02/01	G.S.	0.9164	0.0409	1.9033	0.2388	1.6232	0.8272
02/09/01	G.S.	0.9354	0.0425	1.9170	0.2400	1.6261	0.8240
02/16/01	G.S.	0.9177	0.0413	1.8743	0.2348	1.6115	0.8266
02/23/01	G.S.	0.9145	0.0415	1.8830	0.2347	1.6146	0.8259

Date	Location	Cl	SO_4	Na	K	Mg	Ca
03/02/01	G.S.	0.9177	0.0409	1.8907	0.2364	1.6235	0.8369
03/09/01	G.S.	0.9118	0.0412	1.8958	0.2373	1.6325	0.8413
03/16/01	G.S.	0.9059	0.0411	1.9018	0.2378	1.6477	0.8488
03/23/01	G.S.	0.9183	0.0415	1.8978	0.2378	1.6430	0.8477
07/27/01	G.S.	0.9044	0.0412	1.8900	0.2405	1.5993	0.8741
08/24/01	G.S.	0.1072	0.0043	0.0786	0.0089	0.0556	0.0780
07/13/01	G.S.	0.9050	0.0413	1.8873	0.2403	1.5936	0.8619
08/10/01	G.S.	0.8936	0.0444	1.8949	0.2404	1.5977	0.8671
03/09/01	G.S.	0.9163	0.0414	1.8993	0.2393	1.6472	0.8495
03/16/01	G.S.	0.9114	0.0407	1.8944	0.2379	1.6433	0.8447
03/23/01	G.S.	0.9244	0.0407	1.9030	0.2394	1.6455	0.8471
03/30/01	G.S.	0.9190	0.0413	1.9030	0.2399	1.6679	0.8860
04/06/01	G.S.	0.9199	0.0412	no data	no data	no data	no data
04/13/01	G.S.	0.9198	0.0413	1.8963	0.2375	1.6570	0.8787
04/20/01	G.S.	0.9240	0.0416	1.9196	0.2392	1.6739	0.8803
04/27/01	G.S.	0.8855	0.0406	1.9016	0.2383	1.6628	0.8803
05/05/01	G.S.	0.3730	0.0149	1.6447	0.2067	1.4442	0.7848
05/11/01	G.S.	0.6062	0.0267	1.7899	0.2231	1.5389	0.7128
05/18/01	G.S.	0.9249	0.0421	1.9171	0.2383	1.6706	0.8593
05/25/01	G.S.	0.9148	0.0411	1.9158	0.2391	1.6740	0.8639
06/02/01	G.S.	0.9064	0.0412	1.9053	0.2366	1.6547	0.8524
06/08/01	G.S.	0.9153	0.0413	1.9125	0.2434	1.6492	0.8901
06/15/01	G.S.	0.9156	0.0413	1.9060	0.2425	1.6419	0.8920
06/22/01	G.S.	0.8971	0.0412	1.9006	0.2431	1.6466	0.9004
06/29/01	G.S.	0.8991	0.0410	1.8952	0.2428	1.6342	0.8904
07/06/01	G.S.	0.9053	0.0413	1.8873	0.2407	1.5974	0.8675
07/13/01	G.S.	0.9059	0.0414	1.8983	0.2440	1.6060	0.8729
07/20/01	G.S.	0.4189	0.0193	1.8825	0.2408	1.5909	0.8637
07/27/01	G.S.	0.9002	0.0416	1.8879	0.2406	1.5989	0.8713
08/03/01	G.S.	0.8983	0.0408	1.9015	0.2449	1.6073	0.8746
08/10/01	G.S.	0.8662	0.0392	1.8891	0.2385	1.5929	0.8660
08/17/01	G.S.	0.9089	0.0405	1.8897	0.2373	1.5959	0.8773
08/24/01	G.S.	0.3587	0.0145	1.8942	0.2412	1.5988	0.8803
08/31/01	G.S.	0.9142	0.0411	1.8594	0.2432	1.5802	0.8457
09/07/01	G.S.	0.9090	0.0416	1.9054	0.2419	1.6119	0.8857
09/14/01	G.S.	0.8883	0.0399	1.9081	0.2392	1.6046	0.8806
09/21/01	G.S.	0.9105	0.0419	1.9180	0.2445	1.6086	0.8817
09/28/01	G.S.	0.8648	0.0390	0.4448	0.0548	0.4257	0.4518
10/05/01	G.S.	0.8334	0.0380	1.8754	0.2389	1.5822	0.8516
10/12/01	G.S.	0.9023	0.0406	1.8755	0.2386	1.5854	0.8638
10/19/01	G.S.	0.9034	0.0410	1.8755	0.2356	1.5778	0.8617
10/26/01	G.S.	0.9012	0.0405	1.8949	0.2371	1.5684	0.8606
11/02/01	G.S.	0.9025	0.0413	1.8923	0.2380	1.5912	0.8793
11/09/01	G.S.	0.8887	0.0400	1.8781	0.2385	1.5673	0.8601

Date	Location	Cl	SO_4	Na	K	Mg	Ca
11/16/01	G.S.	0.9060	0.0407	1.8796	0.2338	1.5942	0.8849
11/23/01	G.S.	0.4474	0.0204	1.8745	0.2334	1.5685	0.8723
11/30/01	G.S.	0.2135	0.0084	0.7765	0.1031	0.8552	0.5802
12/07/01	G.S.	0.3059	0.0127	1.7844	0.2278	1.4899	0.8228
12/14/01	G.S.	0.1649	0.0060	1.7904	0.2251	1.5048	0.8346
12/21/01	G.S.	0.1623	0.0069	0.1574	0.0201	0.2462	0.5362
12/28/01	G.S.	0.7119	0.0317	1.8876	0.2417	1.5927	0.8909
01/04/02	G.S.	0.7168	0.0316	1.8871	0.2377	1.5986	0.9081
01/11/02	G.S.	0.7018	0.0316	1.8863	0.2371	1.5784	0.8864
01/18/02	G.S.	0.6839	0.0299	1.8847	0.2390	1.5908	0.9065
01/25/02	G.S.	0.4878	0.0219	1.8836	0.2391	1.5649	0.8809
02/01/02	G.S.	0.6758	0.0306	1.8816	0.2440	1.5639	0.8811
02/08/02	G.S.	0.7161	0.0317	1.8849	0.2393	1.5830	0.8953
02/15/02	G.S.	0.6934	0.0318	1.9121	0.2434	1.6311	0.9150
02/22/02	G.S.	0.8996	0.0393	1.9136	0.2434	1.6275	0.9168
03/01/02	G.S.	0.8913	0.0409	1.9119	0.2418	1.6304	0.9226
03/08/02	G.S.	0.8937	0.0413	1.9186	0.2436	1.6354	0.9287
03/15/02	G.S.	0.9096	0.0425	1.9004	0.2416	1.5851	0.8861
03/24/02	G.S.	0.8916	0.0389	1.9040	0.2425	1.5903	0.8921
03/29/02	G.S.	0.8915	0.0402	1.9014	0.2395	1.5832	0.8916
04/05/02	G.S.	0.9409	0.0483	1.8992	0.2406	1.5326	0.8454
04/12/02	G.S.	0.9467	0.0504	1.8970	0.2399	1.5353	0.8485
04/19/02	G.S.	0.9353	0.0476	1.8977	0.2408	1.5352	0.8462
04/26/02	G.S.	0.9408	0.0491	1.9013	0.2359	1.5369	0.8476
05/03/02	G.S.	0.9603	0.0473	1.9025	0.2380	1.5385	0.8468
05/17/02	G.S.	0.9493	0.0491	1.8926	0.2375	1.5291	0.8415
05/24/02	G.S.	0.9148	0.0411	1.9012	0.2386	1.5333	0.8427
05/31/02	G.S.	0.9064	0.0412	1.9038	0.2412	1.5359	0.8469
06/07/02	G.S.	0.9153	0.0413	1.8992	0.2392	1.5347	0.8456
06/14/02	G.S.	0.9156	0.0413	1.8992	0.2408	1.5337	0.8438
06/21/02	G.S.	0.8971	0.0412	1.8986	0.2327	1.5337	0.8452
06/28/02	G.S.	0.8991	0.0410	1.9045	0.2319	1.5815	0.8638
07/05/02	G.S.	0.9053	0.0413	1.8734	0.2289	1.5573	0.8513
07/12/02	G.S.	0.9059	0.0414	1.8983	0.2440	1.6060	0.8729
07/19/02	G.S.	0.8907	0.0411	1.9013	0.2286	1.5707	0.8625
07/26/02	G.S.	0.8934	0.0417	1.8934	0.2285	1.5607	0.8582
08/02/02	G.S.	0.8901	0.0408	1.8934	0.2304	1.5566	0.8548
08/09/02	G.S.	0.8516	0.0386	1.8973	0.2315	1.5668	0.8617
08/16/02	G.S.	0.8845	0.0405	1.8855	0.2288	1.5513	0.8416
08/23/02	G.S.	0.8956	0.0414	1.8813	0.2318	1.5518	0.8567
08/30/02	G.S.	0.8933	0.0413	1.8919	0.2317	1.5601	0.8567
09/06/02	G.S.	0.8940	0.0410	0.8607	0.1044	0.7073	0.3886
09/13/02	G.S.	0.9112	0.0406	1.8945	0.2305	1.5640	0.8661
09/20/02	G.S.	0.8912	0.0411	1.8947	0.2308	1.5583	0.8552

Date	Location	Cl	SO_4	Na	K	Mg	Ca
09/27/02	G.S.	0.9090	0.0420	1.8925	0.2308	1.5518	0.8587
10/03/02	G.S.	0.8988	0.0415	1.8931	0.2269	1.5487	0.8522
10/10/02	G.S.	0.9002	0.0402	1.8976	0.2319	1.5568	0.8557
10/17/02	G.S.	0.9001	0.0413	1.9062	0.2339	1.5651	0.8646
10/24/02	G.S.	0.9006	0.0417	1.9133	0.2465	1.5722	0.8754
10/31/02	G.S.	0.8994	0.0412	1.9013	0.2305	1.5569	0.8480
11/07/02	G.S.	0.9264	0.0407	1.9254	0.2219	1.5606	0.8645
11/14/02	G.S.	0.9202	0.0412	1.8999	0.2237	1.5669	0.8659
11/21/02	G.S.	0.9007	0.0410	1.8971	0.2300	1.5502	0.8439
11/28/02	G.S.	0.9020	0.0408	1.8935	0.2230	1.5573	0.8733
02/06/00	Arbo4	0.0249	0.0036	0.0194	0.0122	0.0037	0.0089
02/14/00	Arbo4	0.0745	0.0064	0.0952	0.0097	0.0129	0.0402
02/21/00	Arbo4	0.0425	0.0060	0.0756	0.0152	0.0151	0.1321
02/28/00	Arbo4	0.0571	0.0023	0.0662	0.0091	0.0103	0.0092
03/06/00	Arbo4	0.0564	0.0025	0.0610	0.0099	0.0120	0.0105
03/13/00	Arbo4	0.0559	0.0024	0.0627	0.0102	0.0125	0.0102
03/23/00	Arbo4	0.0506	0.0023	0.0716	0.0093	0.0138	0.0120
03/30/00	Arbo4	0.0506	0.0024	0.0538	0.0089	0.0122	0.0103
04/06/00	Arbo4	0.0505	0.0024	0.0622	0.0084	0.0123	0.0109
04/13/00	Arbo4	0.0547	0.0029	0.0651	0.0108	0.0125	0.0120
04/20/00	Arbo4	0.0592	0.0026	0.0671	0.0110	0.0143	0.0126
04/27/00	Arbo4	0.0628	0.0027	0.0644	0.0116	0.0137	0.0123
05/04/00	Arbo4	0.0587	0.0024	0.0667	0.0102	0.0142	0.0133
05/11/00	Arbo4	0.0651	0.0029	0.0701	0.0135	0.0147	0.0142
05/18/00	Arbo4	0.0625	0.0029	0.0687	0.0144	0.0172	0.0150
05/25/00	Arbo4	0.0576	0.0029	0.0643	0.0123	0.0135	0.0104
06/01/00	Arbo4	0.0557	0.0026	0.0694	0.0135	0.0128	0.0122
06/08/00	Arbo4	0.0598	0.0028	0.0604	0.0107	0.0112	0.0094
06/15/00	Arbo4	0.0443	0.0040	0.0464	0.0199	0.0142	0.0128
06/22/00	Arbo4	0.0532	0.0025	0.0572	0.0102	0.0103	0.0080
06/29/00	Arbo4	0.0619	0.0029	0.0591	0.0099	0.0113	0.0089
07/06/00	Arbo4	0.0549	0.0026	0.0480	0.0098	0.0109	0.0080
07/13/00	Arbo4	0.0598	0.0024	0.0592	0.0089	0.0105	0.0078
07/20/00	Arbo4	0.0583	0.0024	0.0478	0.0079	0.0104	0.0079
07/27/00	Arbo4	0.0519	0.0026	0.0550	0.0078	0.0095	0.0081
08/03/00	Arbo4	0.0578	0.0024	0.0475	0.0077	0.0100	0.0072
08/10/00	Arbo4	0.0555	0.0025	0.0555	0.0081	0.0096	0.0075
08/17/00	Arbo4	0.0494	0.0027	0.0412	0.0109	0.0097	0.0075
08/24/00	Arbo4	0.0584	0.0028	0.0549	0.0107	0.0109	0.0086
08/31/00	Arbo4	0.0577	0.0025	0.0493	0.0078	0.0105	0.0079
09/07/00	Arbo4	0.0581	0.0024	0.0573	0.0081	0.0113	0.0084
09/14/00	Arbo4	0.0557	0.0025	0.0591	0.0083	0.0116	0.0085
09/21/00	Arbo4	0.0574	0.0026	0.0588	0.0099	0.0118	0.0095

Date	Location	Cl	SO_4	Na	K	Mg	Ca
09/28/00	Arbo4	0.0567	0.0028	0.0587	0.0099	0.0115	0.0088
10/05/00	Arbo4	0.0567	0.0027	0.0586	0.0119	0.0147	0.0117
10/12/00	Arbo4	0.0584	0.0027	0.0585	0.0094	0.0132	0.0131
10/19/00	Arbo4	0.0534	0.0030	0.0544	0.0120	0.0131	0.0121
10/26/00	Arbo4	0.0586	0.0025	0.0497	0.0096	0.0122	0.0114
11/02/00	Arbo4	0.0554	0.0028	0.0532	0.0109	0.0119	0.0119
11/09/00	Arbo4	0.0580	0.0026	0.0657	0.0102	0.0110	0.0118
11/16/00	Arbo4	0.0581	0.0025	0.0572	0.0098	0.0114	0.0107
11/23/00	Arbo4	0.0577	0.0026	0.0564	0.0099	0.0111	0.0125
11/30/00	Arbo4	0.0584	0.0033	0.0537	0.0154	0.0145	0.0132
12/07/00	Arbo4	0.0585	0.0026	0.0508	0.0085	0.0105	0.0100
12/14/00	Arbo4	0.0692	0.0030	0.0631	0.0133	0.0132	0.0126
12/21/00	Arbo4	0.0579	0.0025	0.0559	0.0094	0.0112	0.0095
12/28/00	Arbo4	0.0567	0.0025	0.0595	0.0087	0.0112	0.0100
01/04/01	Arbo4	0.0596	0.0025	0.0609	0.0099	0.0101	0.0098
01/11/01	Arbo4	0.0589	0.0024	0.0553	0.0076	0.0103	0.0085
01/18/01	Arbo4	0.0581	0.0025	0.0561	0.0080	0.0112	0.0107
01/25/01	Arbo4	0.0465	0.0030	0.0503	0.0118	0.0115	0.0106
02/01/01	Arbo4	0.0561	0.0021	0.0527	0.0086	0.0117	0.0087
02/08/01	Arbo4	0.0951	0.0037	0.0961	0.0235	0.0223	0.0188
02/15/01	Arbo4	0.0624	0.0020	0.0558	0.0094	0.0129	0.0105
02/22/01	Arbo4	0.0567	0.0022	0.0549	0.0089	0.0135	0.0111
03/01/01	Arbo4	0.0559	0.0022	0.0556	0.0084	0.0134	0.0101
03/08/01	Arbo4	0.0675	0.0023	0.0598	0.0106	0.0156	0.0114
03/15/01	Arbo4	0.0551	0.0021	0.0589	0.0075	0.0110	0.0059
03/22/01	Arbo4	0.0673	0.0025	0.0627	0.0133	0.0174	0.0132
03/29/01	Arbo4	0.0645	0.0024	0.0622	0.0109	0.0160	0.0122
04/05/01	Arbo4	0.0544	0.0023	0.0603	0.0097	0.0166	0.0129
04/12/01	Arbo4	0.0740	0.0030	0.0706	0.0143	0.0183	0.0140
04/19/01	Arbo4	0.0654	0.0027	0.0662	0.0115	0.0163	0.0133
04/26/01	Arbo4	0.0581	0.0022	0.0650	0.0107	0.0155	0.0127
05/03/01	Arbo4	0.0618	0.0022	0.0654	0.0112	0.0164	0.0129
05/10/01	Arbo4	0.0556	0.0022	0.0603	0.0108	0.0146	0.0122
05/17/01	Arbo4	0.0327	0.0017	0.0602	0.0106	0.0143	0.0117
05/24/01	Arbo4	0.0544	0.0022	0.0613	0.0102	0.0152	0.0121
05/31/01	Arbo4	0.0539	0.0034	0.0518	0.0277	0.0175	0.0160
06/07/01	Arbo4	0.0595	0.0028	0.0616	0.0122	0.0121	0.0085
06/14/01	Arbo4	0.0617	0.0021	0.0642	0.0101	0.0145	0.0084
06/21/01	Arbo4	0.0652	0.0027	0.0600	0.0118	0.0150	0.0104
07/06/01	Arbo4	0.0595	0.0027	0.0513	0.0103	0.0105	0.0076
07/12/01	Arbo4	0.0574	0.0021	0.0509	0.0071	0.0096	0.0066
07/19/01	Arbo4	0.0582	0.0020	0.0508	0.0074	0.0094	0.0049
07/26/01	Arbo4	0.0585	0.0018	0.0528	0.0066	0.0108	0.0066
08/02/01	Arbo4	0.0581	0.0018	0.0584	0.0114	0.0102	0.0065

Date	Location	Cl	SO_4	Na	K	Mg	Ca
08/16/01	Arbo4	0.0555	0.0020	0.0519	0.0080	0.0105	0.0069
08/23/01	Arbo4	0.0564	0.0018	0.0539	0.0070	0.0109	0.0080
08/30/01	Arbo4	0.0567	0.0018	0.0527	0.0077	0.0100	0.0068
09/06/01	Arbo4	0.0551	0.0018	0.0557	0.0079	0.0113	0.0081
09/13/01	Arbo4	0.0538	0.0021	0.0560	0.0103	0.0115	0.0078
09/20/01	Arbo4	0.0562	0.0020	0.0514	0.0087	0.0110	0.0084
09/27/01	Arbo4	0.0559	0.0020	0.0012	0.0000	0.0022	0.0007
10/04/01	Arbo4	0.0100	0.0000	0.0691	0.0346	0.0074	0.0111
10/11/01	Arbo4	0.0552	0.0019	0.0528	0.0076	0.0094	0.0046
10/18/01	Arbo4	0.0567	0.0020	0.0511	0.0069	0.0092	0.0044
10/25/01	Arbo4	0.0561	0.0019	0.0569	0.0082	0.0094	0.0049
11/01/01	Arbo4	0.0565	0.0023	0.0603	0.0089	0.0111	0.0068
11/08/01	Arbo4	0.0524	0.0024	0.0515	0.0109	0.0091	0.0055
11/15/01	Arbo4	0.0568	0.0020	0.0514	0.0076	0.0091	0.0051
11/22/01	Arbo4	0.0554	0.0025	0.0480	0.0075	0.0094	0.0039
11/29/01	Arbo4	0.0355	0.0018	0.0224	0.0034	0.0043	0.0016
12/06/01	Arbo4	0.0254	0.0023	0.0295	0.0117	0.0076	0.0040
12/13/01	Arbo4	0.0338	0.0021	0.0440	0.0085	0.0079	0.0040
12/20/01	Arbo4	0.0411	0.0019	0.0476	0.0068	0.0084	0.0032
12/27/01	Arbo4	0.0382	0.0019	0.0466	0.0088	0.0100	0.0048
01/03/02	Arbo4	0.0427	0.0019	0.0514	0.0067	0.0101	0.0041
01/10/02	Arbo4	0.0458	0.0017	0.0549	0.0073	0.0098	0.0047
01/17/02	Arbo4	0.0437	0.0018	0.0527	0.0067	0.0098	0.0039
01/24/02	Arbo4	0.0452	0.0016	0.0533	0.0073	0.0100	0.0048
01/31/02	Arbo4	0.0562	0.0017	0.0663	0.0100	0.0260	0.0287
02/07/02	Arbo4	0.0461	0.0017	0.0592	0.0077	0.0105	0.0058
02/14/02	Arbo4	0.0473	0.0016	0.0587	0.0077	0.0116	0.0056
02/21/02	Arbo4	0.0657	0.0000	0.0595	0.0075	0.0124	0.0062
02/28/02	Arbo4	0.0921	0.0000	0.0586	0.0081	0.0128	0.0065
03/07/02	Arbo4	0.0832	0.0000	0.0602	0.0080	0.0134	0.0080
03/14/02	Arbo4	0.0760	0.0063	0.0606	0.0086	0.0138	0.0077
03/24/02	Arbo4	0.0897	0.0064	0.0603	0.0092	0.0142	0.0077
03/28/02	Arbo4	0.0915	0.0000	0.0601	0.0095	0.0140	0.0076
04/04/02	Arbo4	no data	no data	0.0697	0.0135	0.0168	0.0152
04/11/02	Arbo4	0.0922	0.0067	0.0668	0.0155	0.0167	0.0151
04/18/02	Arbo4	0.0815	0.0070	0.0637	0.0133	0.0162	0.0153
04/25/02	Arbo4	0.0987	0.0068	0.0654	0.0149	0.0159	0.0141
05/02/02	Arbo4	0.0846	0.0000	0.0640	0.0131	0.0162	0.0154
05/09/02	Arbo4	0.0935	0.0069	0.0601	0.0123	0.0116	0.0116
05/16/02	Arbo4	0.0858	0.0070	0.0543	0.0111	0.0094	0.0085
05/23/02	Arbo4	0.0583	0.0024	0.0536	0.0103	0.0096	0.0096
05/30/02	Arbo4	0.0577	0.0037	0.0544	0.0107	0.0108	0.0103
06/06/02	Arbo4	0.0637	0.0030	0.0757	0.0081	0.0026	0.0049
06/13/02	Arbo4	0.0660	0.0023	0.0093	0.0059	0.0025	0.0042

Date	Location	Cl	SO_4	Na	K	Mg	Ca
06/20/02	Arbo4	0.0697	0.0029	0.0550	0.0110	0.0086	0.0040
06/27/02	Arbo4	0.2384	0.0030	0.0495	0.0106	0.0091	0.0094
07/04/02	Arbo4	0.0636	0.0030	0.0520	0.0110	0.0091	0.0091
07/11/02	Arbo4	0.0614	0.0023	0.0509	0.0071	0.0096	0.0066
07/18/02	Arbo4	0.0558	0.0000	0.0541	0.0091	0.0085	0.0083
07/25/02	Arbo4	0.0554	0.0000	0.0584	0.0087	0.0094	0.0089
08/01/02	Arbo4	0.0541	0.0030	0.0530	0.0097	0.0093	0.0083
08/08/02	Arbo4	0.0541	0.0000	0.0622	0.0101	0.0092	0.0100
08/15/02	Arbo4	0.0630	0.0032	0.0548	0.0102	0.0099	0.0101
08/22/02	Arbo4	0.0443	0.0030	0.0446	0.0097	0.0077	0.0079
08/29/02	Arbo4	0.0562	0.0030	0.0536	0.0095	0.0079	0.0070
09/05/02	Arbo4	0.0561	0.0028	0.0533	0.0090	0.0091	0.0000
09/12/02	Arbo4	0.0567	0.0000	0.0555	0.0088	0.0089	0.0087
09/19/02	Arbo4	0.0527	0.0029	0.0524	0.0103	0.0085	0.0089
09/26/02	Arbo4	0.0563	0.0031	0.0526	0.0106	0.0078	0.0000
10/03/02	Arbo4	0.0553	0.0030	0.0551	0.0102	0.0092	0.0090
10/10/02	Arbo4	0.0553	0.0030	0.0573	0.0108	0.0099	0.0111
10/17/02	Arbo4	0.0540	0.0028	0.0570	0.0104	0.0094	0.0105
10/24/02	Arbo4	0.0564	0.0030	0.0644	0.0117	0.0125	0.0119
10/31/02	Arbo4	0.0585	0.0031	0.0558	0.0103	0.0100	0.0097
11/07/02	Arbo4	0.0595	0.0031	0.0574	0.0113	0.0116	0.0104
11/14/02	Arbo4	0.0539	0.0029	0.0559	0.0106	0.0103	0.0104
11/21/02	Arbo4	0.0554	0.0029	0.0530	0.0095	0.0083	0.0095
11/28/02	Arbo4	0.0764	0.0037	0.0588	0.0160	0.0142	0.0147
02/14/00	Taco8	0.0664	0.0045	0.0623	0.0087	0.0101	0.0111
02/21/00	Taco8	0.0145	0.0026	0.0530	0.0094	0.0090	0.0118
02/28/00	Taco8	0.0575	0.0023	0.1064	0.0110	0.0133	0.0433
03/06/00	Taco8	0.0581	0.0023	0.0679	0.0119	0.0118	0.0130
03/16/00	Taco8	0.0592	0.0024	0.0682	0.0113	0.0118	0.0127
03/23/00	Taco8	0.0577	0.0023	0.0702	0.0116	0.0126	0.0132
03/30/00	Taco8	0.0535	0.0023	0.0728	0.0123	0.0123	0.0141
04/06/00	Taco8	0.0553	0.0024	0.0757	0.0130	0.0130	0.0140
04/13/00	Taco8	0.0581	0.0027	0.0744	0.0144	0.0134	0.0135
04/20/00	Taco8	0.0599	0.0029	0.0738	0.0147	0.0131	0.0144
04/27/00	Taco8	0.0617	0.0030	0.0765	0.0167	0.0142	0.0155
05/04/00	Taco8	0.0635	0.0025	0.0754	0.0140	0.0146	0.0154
05/11/00	Taco8	0.0627	0.0034	0.0782	0.0199	0.0154	0.0176
05/18/00	Taco8	0.0620	0.0029	0.0766	0.0190	0.0156	0.0171
05/25/00	Taco8	0.0578	0.0031	0.0722	0.0162	0.0124	0.0120
06/01/00	Taco8	0.0591	0.0026	0.0623	0.0108	0.0127	0.0103
06/08/00	Taco8	0.0586	0.0046	0.0652	0.0139	0.0125	0.0115
06/15/00	Taco8	0.0565	0.0025	0.0694	0.0130	0.0124	0.0120
06/22/00	Taco8	0.0546	0.0025	0.0609	0.0101	0.0101	0.0100

Date	Location	Cl	SO_4	Na	K	Mg	Ca
06/29/00	Taco8	0.0592	0.0024	0.0494	0.0093	0.0105	0.0095
07/06/00	Taco8	0.0576	0.0025	0.0616	0.0091	0.0109	0.0095
07/13/00	Taco8	0.0569	0.0025	0.0653	0.0100	0.0108	0.0099
07/20/00	Taco8	0.0562	0.0023	0.0523	0.0091	0.0101	0.0091
07/27/00	Taco8	0.0567	0.0025	0.0581	0.0080	0.0100	0.0093
08/03/00	Taco8	0.0583	0.0023	0.0601	0.0091	0.0109	0.0097
08/10/00	Taco8	0.0549	0.0023	0.0589	0.0093	0.0098	0.0087
08/17/00	Taco8	0.0566	0.0022	0.0630	0.0094	0.0102	0.0094
08/24/00	Taco8	0.0565	0.0025	0.0597	0.0086	0.0098	0.0089
08/31/00	Taco8	0.0576	0.0024	0.0630	0.0100	0.0111	0.0101
09/07/00	Taco8	0.0577	0.0022	0.0612	0.0092	0.0116	0.0105
09/14/00	Taco8	0.0585	0.0025	0.0644	0.0104	0.0123	0.0115
09/21/00	Taco8	0.0578	0.0024	0.0643	0.0112	0.0125	0.0116
09/28/00	Taco8	0.0574	0.0024	0.0631	0.0113	0.0116	0.0104
10/05/00	Taco8	0.0577	0.0024	0.0689	0.0116	0.0123	0.0115
10/12/00	Taco8	0.0599	0.0026	0.0648	0.0123	0.0123	0.0142
10/19/00	Taco8	0.0591	0.0030	0.0597	0.0150	0.0127	0.0140
10/26/00	Taco8	0.0570	0.0024	0.0673	0.0112	0.0227	0.0308
11/02/00	Taco8	0.0541	0.0027	0.0587	0.0118	0.0115	0.0140
11/09/00	Taco8	0.0580	0.0026	0.0664	0.0099	0.0118	0.0126
11/16/00	Taco8	0.0563	0.0023	0.0642	0.0126	0.0130	0.0149
11/23/00	Taco8	0.0627	0.0028	0.0638	0.0107	0.0121	0.0138
11/30/00	Taco8	0.0606	0.0028	0.0633	0.0121	0.0110	0.0135
12/07/00	Taco8	0.0576	0.0023	0.0621	0.0110	0.0109	0.0116
12/14/00	Taco8	0.0589	0.0024	0.0625	0.0113	0.0123	0.0130
12/21/00	Taco8	0.0585	0.0024	0.0630	0.0115	0.0116	0.0131
12/28/00	Taco8	0.0572	0.0024	0.0614	0.0113	0.0105	0.0105
01/04/01	Taco8	0.0669	0.0026	0.0656	0.0100	0.0115	0.0125
01/11/01	Taco8	0.0576	0.0023	0.0649	0.0092	0.0109	0.0128
01/18/01	Taco8	0.0542	0.0024	0.0619	0.0104	0.0110	0.0127
01/25/01	Taco8	0.0502	0.0027	0.0537	0.0126	0.0097	0.0101
02/01/01	Taco8	0.0572	0.0020	0.0586	0.0105	0.0122	0.0112
02/08/01	Taco8	0.0608	0.0022	0.0614	0.0121	0.0129	0.0120
02/15/01	Taco8	0.0680	0.0022	0.0968	0.0151	0.0148	0.0135
02/22/01	Taco8	0.0594	0.0021	0.0677	0.0121	0.0137	0.0130
03/01/01	Taco8	0.0569	0.0021	0.0653	0.0119	0.0135	0.0123
03/08/01	Taco8	0.0694	0.0022	0.0711	0.0141	0.0152	0.0140
03/15/01	Taco8	0.0592	0.0022	0.0675	0.0112	0.0128	0.0086
03/22/01	Taco8	0.0618	0.0023	0.0712	0.0143	0.0152	0.0142
03/29/01	Taco8	0.0668	0.0026	0.0717	0.0147	0.0153	0.0140
04/05/01	Taco8	0.0598	0.0027	0.0808	0.0161	0.0168	0.0163
04/12/01	Taco8	0.0705	0.0029	0.0760	0.0188	0.0173	0.0154
04/19/01	Taco8	0.0676	0.0028	0.0693	0.0141	0.0151	0.0128
04/26/01	Taco8	0.0608	0.0020	0.0790	0.0167	0.0168	0.0165

Date	Location	Cl	SO_4	Na	K	Mg	Ca
05/03/01	Taco8	0.0643	0.0021	0.0739	0.0158	0.0163	0.0159
05/10/01	Taco8	0.0589	0.0019	0.0742	0.0154	0.0167	0.0168
05/17/01	Taco8	0.0584	0.0022	0.0719	0.0155	0.0145	0.0141
05/24/01	Taco8	0.0570	0.0021	0.0740	0.0154	0.0159	0.0150
05/31/01	Taco8	0.0614	0.0023	0.0709	0.0165	0.0170	0.0166
06/07/01	Taco8	0.0544	0.0031	0.0550	0.0213	0.0146	0.0136
06/14/01	Taco8	0.0682	0.0022	0.0731	0.0139	0.0137	0.0115
06/21/01	Taco8	0.0687	0.0027	0.0645	0.0126	0.0135	0.0110
07/06/01	Taco8	0.0593	0.0021	0.0570	0.0081	0.0093	0.0077
07/12/01	Taco8	0.0582	0.0020	0.0543	0.0072	0.0100	0.0085
07/19/01	Taco8	0.0588	0.0019	0.0555	0.0081	0.0100	0.0085
07/26/01	Taco8	0.0572	0.0018	0.0579	0.0079	0.0105	0.0084
08/03/01	Taco8	0.0073	0.0000	0.0599	0.0091	0.0110	0.0090
08/16/01	Taco8	0.0549	0.0024	0.0513	0.0101	0.0104	0.0102
08/23/01	Taco8	0.0573	0.0018	0.0602	0.0092	0.0119	0.0101
08/30/01	Taco8	0.0580	0.0017	0.0569	0.0092	0.0108	0.0093
09/06/01	Taco8	0.0566	0.0018	0.0659	0.0097	0.0112	0.0104
09/13/01	Taco8	0.0590	0.0019	0.0614	0.0100	0.0118	0.0100
09/20/01	Taco8	0.0566	0.0019	0.0640	0.0131	0.0113	0.0092
09/27/01	Taco8	0.0230	0.0022	0.0211	0.0056	0.0043	0.0024
10/04/01	Taco8	0.0228	0.0019	0.0044	0.0013	0.0021	0.0002
10/11/01	Taco8	0.0555	0.0018	0.0600	0.0090	0.0101	0.0073
10/18/01	Taco8	0.0558	0.0019	0.0562	0.0083	0.0089	0.0060
10/25/01	Taco8	0.0285	0.0045	0.0598	0.0094	0.0098	0.0065
11/01/01	Taco8	0.0577	0.0018	0.0601	0.0099	0.0100	0.0072
11/08/01	Taco8	0.0497	0.0025	0.0507	0.0093	0.0083	0.0058
11/15/01	Taco8	0.0575	0.0019	0.0534	0.0076	0.0082	0.0055
11/22/01	Taco8	0.0469	0.0024	0.0472	0.0078	0.0110	0.0049
11/29/01	Taco8	0.0473	0.0018	0.0287	0.0034	0.0049	0.0026
12/06/01	Taco8	0.0364	0.0016	0.0425	0.0055	0.0061	0.0039
12/13/01	Taco8	0.0312	0.0022	0.0383	0.0072	0.0074	0.0047
12/20/01	Taco8	0.0420	0.0017	0.0526	0.0071	0.0081	0.0048
12/27/01	Taco8	0.0372	0.0019	0.0476	0.0116	0.0090	0.0053
01/03/02	Taco8	0.0405	0.0017	0.0565	0.0081	0.0090	0.0056
01/10/02	Taco8	0.0468	0.0016	0.0613	0.0081	0.0104	0.0065
01/17/02	Taco8	0.0423	0.0016	0.0574	0.0080	0.0089	0.0055
01/24/02	Taco8	0.0436	0.0000	0.0593	0.0086	0.0105	0.0065
01/31/02	Taco8	0.0544	0.0018	0.0662	0.0104	0.0109	0.0072
02/07/02	Taco8	0.0443	0.0000	0.0626	0.0085	0.0097	0.0069
02/14/02	Taco8	0.0421	0.0022	0.0642	0.0098	0.0114	0.0067
02/21/02	Taco8	0.0669	0.0000	0.0745	0.0099	0.0107	0.0075
02/28/02	Taco8	0.0687	0.0000	0.0684	0.0116	0.0124	0.0080
03/07/02	Taco8	0.0783	0.0000	0.0690	0.0115	0.0126	0.0087
03/14/02	Taco8	0.0787	0.0000	0.0718	0.0114	0.0131	0.0096

Date	Location	Cl	SO_4	Na	K	Mg	Ca
03/24/02	Taco8	0.0842	0.0000	0.0717	0.0120	0.0131	0.0088
03/28/02	Taco8	0.0853	0.0000	0.0731	0.0123	0.0136	0.0095
04/04/02	Taco8	no data	no data	0.0758	0.0192	0.0150	0.0177
04/11/02	Taco8	0.0919	0.0000	0.0783	0.0163	0.0160	0.0177
04/18/02	Taco8	0.0849	0.0000	0.0784	0.0156	0.0152	0.0172
04/25/02	Taco8	0.0967	0.0071	0.0752	0.0162	0.0161	0.0168
05/02/02	Taco8	0.0916	0.0000	0.0768	0.0163	0.0153	0.0171
05/09/02	Taco8	0.1060	0.0069	0.0665	0.0143	0.0123	0.0137
05/16/02	Taco8	0.0857	0.0069	0.0564	0.0109	0.0092	0.0099
05/23/02	Taco8	0.0632	0.0025	0.0575	0.0105	0.0103	0.0114
05/30/02	Taco8	0.0681	0.0027	0.0591	0.0114	0.0095	0.0110
06/06/02	Taco8	0.0604	0.0037	0.0619	0.0171	0.0027	0.0047
06/13/02	Taco8	0.0757	0.0027	0.0636	0.0107	0.0084	0.0037
06/20/02	Taco8	0.0763	0.0032	0.0625	0.0198	0.0023	0.0042
06/27/02	Taco8	0.0673	0.0026	no data	no data	no data	no data
07/04/02	Taco8	0.0593	0.0021	0.0561	0.0094	0.0090	0.0099
07/11/02	Taco8	0.0582	0.0020	0.0543	0.0072	0.0100	0.0085
07/18/02	Taco8	0.0553	0.0029	0.0565	0.0100	0.0081	0.0101
07/25/02	Taco8	0.0559	0.0000	0.0598	0.0096	0.0094	0.0106
08/01/02	Taco8	0.0502	0.0030	0.0538	0.0111	0.0085	0.0107
08/08/02	Taco8	0.0381	0.0000	0.0636	0.0105	0.0077	0.0096
08/15/02	Taco8	0.0725	0.0030	0.0666	0.0117	0.0095	0.0109
08/22/02	Taco8	0.0524	0.0031	0.0540	0.0097	0.0075	0.0091
08/29/02	Taco8	0.0551	0.0029	0.0545	0.0095	0.0073	0.0098
09/05/02	Taco8	0.0558	0.0000	0.0579	0.0102	0.0082	0.0109
09/12/02	Taco8	0.0557	0.0000	0.0604	0.0110	0.0088	0.0000
09/19/02	Taco8	0.0536	0.0029	0.0573	0.0107	0.0092	0.0110
09/26/02	Taco8	0.0555	0.0030	0.0541	0.0100	0.0079	0.0100
10/03/02	Taco8	0.0530	0.0000	0.0595	0.0106	0.0094	0.0113
10/10/02	Taco8	0.0556	0.0000	0.0616	0.0120	0.0090	0.0113
10/17/02	Taco8	0.0559	0.0000	0.0641	0.0125	0.0100	0.0122
10/24/02	Taco8	0.0562	0.0029	0.0615	0.0148	0.0108	0.0125
10/31/02	Taco8	0.0569	0.0030	0.0625	0.0131	0.0110	0.0116
11/07/02	Taco8	0.0560	0.0000	0.0629	0.0115	0.0101	0.0121
11/14/02	Taco8	0.0543	0.0000	0.0626	0.0130	0.0097	0.0120
11/21/02	Taco8	0.0529	0.0000	0.0588	0.0108	0.0101	0.0108
11/28/02	Taco8	0.0624	0.0036	0.0615	0.0117	0.0097	0.0112
02/06/00	Well 1	0.0930	0.0091	0.2261	0.0232	0.1559	0.1628
02/14/00	Well 1	0.3870	0.0188	0.7620	0.0787	0.5619	0.5187
02/21/00	Well 1	0.1278	0.0064	no data	no data	no data	no data
02/28/00	Well 1	0.4078	0.0160	0.7846	0.0750	0.5774	0.5162
03/06/00	Well 1	0.4044	0.0173	no data	no data	no data	no data
03/16/00	Well 1	0.4239	0.0164	0.8655	0.0869	0.6301	0.5459

Date	Location	Cl	SO_4	Na	K	Mg	Ca
03/23/00	Well 1	0.4286	0.0167	no data	no data	no data	no data
03/30/00	Well 1	0.4360	0.0179	0.8504	0.0819	0.6323	0.5556
04/06/00	Well 1	0.4301	0.0158	no data	no data	no data	no data
04/13/00	Well 1	0.4183	0.0169	0.8069	0.0765	0.5996	0.5382
04/20/00	Well 1	0.4253	0.0166	no data	no data	no data	no data
04/27/00	Well 1	0.4202	0.0166	0.8712	0.0856	0.6339	0.5625
05/04/00	Well 1	0.4573	0.0172	no data	no data	no data	no data
05/11/00	Well 1	0.4501	0.0194	0.8973	0.0859	0.6749	0.6069
05/18/00	Well 1	0.4467	0.0176	no data	no data	no data	no data
05/25/00	Well 1	0.4225	0.0267	0.8297	0.0796	0.6105	0.5520
06/01/00	Well 1	0.4144	0.0165	no data	no data	no data	no data
06/08/00	Well 1	0.3704	0.0152	0.8143	0.0834	0.5824	0.5204
06/15/00	Well 1	0.3991	0.0154	no data	no data	no data	no data
06/22/00	Well 1	0.3431	0.0140	0.7499	0.0753	0.5484	0.4946
06/29/00	Well 1	0.3486	0.0130	no data	no data	no data	no data
07/06/00	Well 1	0.3612	0.0131	0.7628	0.0740	0.5638	0.5134
07/13/00	Well 1	0.4023	0.0144	no data	no data	no data	no data
07/20/00	Well 1	0.4169	0.0154	0.8362	0.0855	0.6027	0.5373
07/27/00	Well 1	0.2262	0.0096	no data	no data	no data	no data
08/03/00	Well 1	0.4228	0.0151	0.8536	0.0880	0.6174	0.5473
08/10/00	Well 1	0.2547	0.0115	no data	no data	no data	no data
08/17/00	Well 1	0.3824	0.0135	0.7978	0.0811	0.5784	0.5197
08/24/00	Well 1	0.2333	0.0099	no data	no data	no data	no data
08/31/00	Well 1	0.4319	0.0152	0.8943	0.0935	0.6326	0.5573
09/07/00	Well 1	0.4338	0.0155	no data	no data	no data	no data
09/14/00	Well 1	0.4433	0.0155	0.9029	0.0958	0.6242	0.5492
09/21/00	Well 1	0.4489	0.0161	no data	no data	no data	no data
09/28/00	Well 1	0.4115	0.0143	0.8518	0.0884	0.6007	0.5355
10/05/00	Well 1	0.4483	0.0158	no data	no data	no data	no data
10/12/00	Well 1	0.4339	0.0150	0.9121	0.0975	0.6498	0.5735
10/19/00	Well 1	0.4203	0.0149	no data	no data	no data	no data
10/26/00	Well 1	0.4395	0.0148	0.9152	0.1004	0.6435	0.5685
11/02/00	Well 1	0.2350	0.0110	no data	no data	no data	no data
11/09/00	Well 1	0.4174	0.0142	0.8664	0.1008	0.6056	0.5023
11/16/00	Well 1	0.4502	0.0154	no data	no data	no data	no data
11/23/00	Well 1	0.3594	0.0135	0.7777	0.0758	0.5520	0.4672
11/30/00	Well 1	0.4544	0.0151	no data	no data	no data	no data
12/07/00	Well 1	0.4301	0.0145	0.9331	0.0941	0.6453	0.5395
12/14/00	Well 1	0.3952	0.0143	no data	no data	no data	no data
12/21/00	Well 1	0.4474	0.0149	0.9411	0.0958	0.6557	0.5776
12/28/00	Well 1	0.4131	0.0143	no data	no data	no data	no data
01/04/01	Well 1	0.2747	0.0110	0.6387	0.0638	0.4638	0.4151
01/11/01	Well 1	0.4317	0.0145	no data	no data	no data	no data
01/18/01	Well 1	0.4507	0.0151	0.9504	0.1028	0.6610	0.5615

Date	Location	Cl	SO_4	Na	K	Mg	Ca
01/25/01	Well 1	0.2715	0.0132	no data	no data	no data	no data
02/01/01	Well 1	0.4543	0.0148	0.9201	0.1078	0.6556	0.5384
02/08/01	Well 1	0.4475	0.0153	no data	no data	no data	no data
02/15/01	Well 1	0.4535	0.0153	0.9350	0.1074	0.6663	0.5504
03/01/01	Well 1	0.0750	0.0027	0.8827	0.0976	0.6394	0.5396
03/15/01	Well 1	0.4418	0.0148	0.8823	0.0934	0.6547	0.5636
03/29/01	Well 1	0.4481	0.0164	0.8805	0.0918	0.6452	0.5690
04/12/01	Well 1	0.4505	0.0161	0.8781	0.0919	0.6443	0.5661
04/26/01	Well 1	0.4505	0.0151	0.9400	0.1023	0.6892	0.5949
05/10/01	Well 1	0.4503	0.0154	0.4273	0.0451	0.3125	0.4111
05/24/01	Well 1	0.4467	0.0153	0.9015	0.0946	0.6567	0.5663
06/07/01	Well 1	0.4148	0.0190	0.8256	0.0841	0.5631	0.4437
06/21/01	Well 1	0.3605	0.0158	0.8044	0.0854	0.5705	0.5156
07/05/01	Well 1	0.3395	0.0114	0.6641	0.0746	0.5013	0.4557
07/19/01	Well 1	0.3237	0.0115	0.6991	0.0749	0.4981	0.4561
08/02/01	Well 1	0.4203	0.0144	0.8622	0.0941	0.5991	0.5319
08/16/01	Well 1	0.2490	0.0090	0.6143	0.0648	0.4192	0.3751
08/30/01	Well 1	0.3819	0.0130	0.8249	0.0910	0.5760	0.5171
09/13/01	Well 1	0.4440	0.0147	0.9035	0.1008	0.6310	0.5599
09/27/01	Well 1	0.1020	0.0032	0.1617	0.0192	0.1412	0.2908
10/11/01	Well 1	0.4017	0.0133	0.8556	0.0984	0.6068	0.5384
10/25/01	Well 1	0.4458	0.0150	0.9086	0.1051	0.6236	0.5497
11/08/01	Well 1	0.2477	0.0090	0.5786	0.0656	0.3857	0.3406
11/22/01	Well 1	0.1799	0.0066	0.4290	0.0422	0.3079	0.2950
12/08/01	Well 1	0.0972	0.0029	0.0753	0.0097	0.0636	0.0813
12/20/01	Well 1	0.2146	0.0073	0.0703	0.0089	0.0648	0.0568
01/03/02	Well 1	0.3094	0.0106	0.8134	0.0858	0.5793	0.5333
01/17/02	Well 1	0.3219	0.0107	0.8520	0.0909	0.5895	0.5387
01/31/02	Well 1	0.3304	0.0101	0.8572	0.0933	0.6085	0.5578
02/14/02	Well 1	0.3381	0.0115	0.8505	0.0882	0.6016	0.5531
02/28/02	Well 1	no data	no data	0.8462	0.0897	0.6081	0.5646
03/14/02	Well 1	no data	no data	0.8305	0.0840	0.5934	0.5552
03/28/02	Well 1	no data	no data	0.8529	0.0880	0.6017	0.5556
04/11/02	Well 1	no data	no data	0.8556	0.0886	0.6043	0.5180
04/25/02	Well 1	no data	no data	0.8446	0.0890	0.5931	0.5078
05/09/02	Well 1	no data	no data	0.2906	0.0306	0.1980	0.1920
05/23/02	Well 1	no data	no data	0.7915	0.0847	0.5676	0.4911
06/06/02	Well 1	no data	no data	0.7404	0.0809	0.5155	0.4423
06/20/02	Well 1	no data	no data	0.8636	0.0811	0.5671	0.5024
07/04/02	Well 1	no data	no data	0.4936	0.0510	0.3479	0.3304
07/18/02	Well 1	no data	no data	0.7766	0.0818	0.5371	0.4825
08/01/02	Well 1	no data	no data	0.6978	0.0642	0.4641	0.4260
08/15/02	Well 1	no data	no data	0.6423	0.0683	0.4361	0.3955
08/29/02	Well 1	no data	no data	0.5888	0.0615	0.4132	0.3800

Date	Location	Cl	SO_4	Na	K	Mg	Ca
09/12/02	Well 1	no data	no data	0.8758	0.0892	0.6020	0.5434
09/26/02	Well 1	no data	no data	0.6660	0.0716	0.4588	0.4258
03/06/00	Well 2	0.4860	0.0163	no data	no data	no data	no data
03/16/00	Well 2	0.4316	0.0152	0.9861	0.1248	0.6487	0.4837
03/23/00	Well 2	0.5084	0.0189	no data	no data	no data	no data
03/30/00	Well 2	0.5055	0.0199	1.0095	0.1312	0.6999	0.5255
04/06/00	Well 2	0.4855	0.0181	no data	no data	no data	no data
04/13/00	Well 2	0.4717	0.0187	0.9739	0.1263	0.6480	0.4957
04/20/00	Well 2	0.4735	0.0173	no data	no data	no data	no data
04/27/00	Well 2	0.4923	0.0188	0.9590	0.1211	0.6210	0.4763
05/04/00	Well 2	0.5028	0.0185	no data	no data	no data	no data
05/11/00	Well 2	0.4576	0.0165	0.9831	0.1258	0.6741	0.5268
05/18/00	Well 2	0.4898	0.0173	no data	no data	no data	no data
05/25/00	Well 2	0.4523	0.0159	0.9786	0.1234	0.6700	0.5255
06/01/00	Well 2	0.4596	0.0158	no data	no data	no data	no data
06/08/00	Well 2	0.4360	0.0160	0.9494	0.1231	0.6245	0.4849
06/15/00	Well 2	0.4761	0.0174	no data	no data	no data	no data
06/22/00	Well 2	0.4353	0.0169	0.9360	0.1202	0.6049	0.4732
06/29/00	Well 2	0.4460	0.0166	no data	no data	no data	no data
07/06/00	Well 2	0.4546	0.0157	0.9564	0.1246	0.6272	0.4888
07/13/00	Well 2	0.4598	0.0166	no data	no data	no data	no data
07/20/00	Well 2	0.4686	0.0158	0.9638	0.1237	0.6292	0.4902
07/27/00	Well 2	0.4464	0.0155	no data	no data	no data	no data
08/03/00	Well 2	0.4583	0.0150	0.9444	0.1211	0.6121	0.4769
08/10/00	Well 2	0.4642	0.0144	no data	no data	no data	no data
08/17/00	Well 2	0.4536	0.0144	0.9451	0.1222	0.6087	0.4764
08/24/00	Well 2	0.4407	0.0137	no data	no data	no data	no data
08/31/00	Well 2	0.4543	0.0140	0.9460	0.1225	0.6100	0.4780
09/07/00	Well 2	0.4681	0.0151	no data	no data	no data	no data
09/14/00	Well 2	0.4682	0.0145	0.8882	0.1157	0.5797	0.4590
09/21/00	Well 2	0.4806	0.0144	no data	no data	no data	no data
09/28/00	Well 2	0.4771	0.0142	0.9776	0.1258	0.6387	0.5021
10/05/00	Well 2	0.4790	0.0145	no data	no data	no data	no data
10/12/00	Well 2	0.4740	0.0134	0.9538	0.1253	0.6232	0.4939
10/19/00	Well 2	0.4665	0.0139	no data	no data	no data	no data
10/26/00	Well 2	0.4711	0.0136	0.9776	0.1227	0.6328	0.4652
11/02/00	Well 2	0.4353	0.0129	no data	no data	no data	no data
11/09/00	Well 2	0.4531	0.0125	0.9443	0.1143	0.6050	0.4527
11/16/00	Well 2	0.4702	0.0124	no data	no data	no data	no data
11/23/00	Well 2	0.4241	0.0122	0.9072	0.1114	0.5743	0.4316
11/30/00	Well 2	0.2742	0.0097	no data	no data	no data	no data
12/07/00	Well 2	0.4599	0.0143	0.9667	0.1267	0.6209	0.4715
12/14/00	Well 2	0.4602	0.0139	no data	no data	no data	no data

Date	Location	Cl	SO_4	Na	K	Mg	Ca
12/21/00	Well 2	0.4657	0.0135	0.9529	0.1106	0.6218	0.4797
12/28/00	Well 2	0.4430	0.0130	no data	no data	no data	no data
01/04/01	Well 2	0.3993	0.0123	0.8562	0.1021	0.5456	0.4208
01/11/01	Well 2	0.4707	0.0137	no data	no data	no data	no data
01/18/01	Well 2	0.4797	0.0133	0.9550	0.1118	0.6248	0.4811
01/25/01	Well 2	0.4312	0.0131	no data	no data	no data	no data
02/01/01	Well 2	0.4622	0.0145	0.9037	0.1171	0.6003	0.4517
02/08/01	Well 2	0.4778	0.0151	no data	no data	no data	no data
02/15/01	Well 2	0.5041	0.0146	0.9040	0.1170	0.5988	0.4532
03/01/01	Well 2	0.1005	0.0000	0.9357	0.1212	0.6230	0.4708
03/15/01	Well 2	0.4893	0.0152	0.9323	0.1205	0.6265	0.4756
03/29/01	Well 2	0.4850	0.0154	0.9482	0.1215	0.6248	0.4845
04/12/01	Well 2	0.4866	0.0156	0.9356	0.1204	0.6203	0.4842
04/26/01	Well 2	0.4745	0.0140	0.9153	0.1178	0.5973	0.4674
05/10/01	Well 2	0.2543	0.0074	0.1392	0.0200	0.1076	0.1546
05/24/01	Well 2	0.4823	0.0140	0.9093	0.1230	0.6065	0.4661
06/07/01	Well 2	0.4662	0.0138	0.9963	0.1377	0.6417	0.4865
06/21/01	Well 2	0.4637	0.0125	0.9038	0.1175	0.5798	0.4635
07/05/01	Well 2	0.4447	0.0121	0.8999	0.1180	0.5814	0.4619
07/19/01	Well 2	0.4545	0.0128	0.9165	0.1201	0.5863	0.4650
08/02/01	Well 2	0.4661	0.0132	0.9261	0.1212	0.5923	0.4683
08/16/01	Well 2	0.4394	0.0110	0.9188	0.1230	0.6077	0.4871
08/30/01	Well 2	0.4541	0.0117	0.9266	0.1241	0.6061	0.4857
09/13/01	Well 2	0.4474	0.0118	0.9451	0.1260	0.6246	0.5028
09/27/01	Well 2	0.0907	0.0028	0.2769	0.0443	0.1738	0.2209
10/11/01	Well 2	0.4678	0.0136	0.9678	0.1281	0.6352	0.5079
10/25/01	Well 2	0.4703	0.0145	0.9577	0.1259	0.6274	0.5037
11/08/01	Well 2	0.4677	0.0136	0.9602	0.1268	0.6371	0.5103
11/22/01	Well 2	0.4004	0.0132	0.5153	0.0639	0.3602	0.4233
12/08/01	Well 2	0.0940	0.0023	0.1478	0.0189	0.1134	0.1158
12/20/01	Well 2	0.3463	0.0104	0.9023	0.1191	0.5840	0.4699
01/03/02	Well 2	0.3593	0.0105	0.9271	0.1245	0.6078	0.4902
01/17/02	Well 2	0.3679	0.0099	0.9444	0.1255	0.6223	0.4849
01/31/02	Well 2	0.3729	0.0094	0.9542	0.1285	0.6484	0.5234
02/14/02	Well 2	0.3733	0.0110	0.9578	0.1275	0.6678	0.5400
02/28/02	Well 2	0.5036	0.0198	0.9940	0.1302	0.6871	0.5604
03/14/02	Well 2	0.5011	0.0195	0.9716	0.1264	0.6331	0.5051
03/28/02	Well 2	0.5084	0.0212	0.9601	0.1252	0.6146	0.4912
04/11/02	Well 2	0.5311	0.0220	0.9530	0.1203	0.6197	0.4630
04/25/02	Well 2	0.5128	0.0217	0.9482	0.1197	0.6301	0.4709
05/09/02	Well 2	0.4636	0.0185	0.9252	0.1182	0.6037	0.4516
05/23/02	Well 2	no data	no data	0.8977	0.1150	0.5694	0.4267
06/06/02	Well 2	no data	no data	0.9357	0.1183	0.6072	0.4546
06/20/02	Well 2	no data	no data	0.9803	0.1268	0.6189	0.4702

Date	Location	Cl	SO_4	Na	K	Mg	Ca
07/04/02	Well 2	no data	no data	0.9296	0.1206	0.5925	0.4613
07/19/02	Well 2	no data	no data	0.9325	0.1228	0.6179	0.4855
08/01/02	Well 2	no data	no data	0.9148	0.1151	0.5948	0.4663
08/15/02	Well 2	no data	no data	0.9136	0.1182	0.5934	0.4665
09/12/02	Well 2	no data	no data	0.9575	0.1156	0.6209	0.4842
09/26/02	Well 2	no data	no data	0.9753	0.1225	0.6499	0.5100
02/06/00	Well 3	0.0538	0.0075	0.1627	0.0041	0.0924	0.1153
02/14/00	Well 3	0.0961	0.0058	0.2196	0.0151	0.1293	0.1136
02/21/00	Well 3	0.0188	0.0028	no data	no data	no data	no data
02/28/00	Well 3	0.0814	0.0039	0.2268	0.0137	0.1400	0.1243
03/06/00	Well 3	0.1150	0.0046	no data	no data	no data	no data
03/16/00	Well 3	0.1342	0.0047	0.2616	0.0210	0.1634	0.1361
03/23/00	Well 3	0.1478	0.0059	no data	no data	no data	no data
03/30/00	Well 3	0.1511	0.0049	0.2549	0.0207	0.1656	0.1343
04/06/00	Well 3	0.1489	0.0046	no data	no data	no data	no data
04/13/00	Well 3	0.1648	0.0054	0.2824	0.0226	0.1820	0.1458
04/20/00	Well 3	0.1627	0.0048	no data	no data	no data	no data
04/27/00	Well 3	0.1653	0.0047	0.2918	0.0236	0.1931	0.1587
05/04/00	Well 3	0.1735	0.0047	no data	no data	no data	no data
05/11/00	Well 3	0.1809	0.0049	0.2995	0.0237	0.2032	0.1684
05/18/00	Well 3	0.1990	0.0052	no data	no data	no data	no data
05/25/00	Well 3	0.1861	0.0048	0.3012	0.0242	0.2081	0.1678
06/01/00	Well 3	0.1899	0.0050	no data	no data	no data	no data
06/08/00	Well 3	0.1713	0.0048	0.3042	0.0236	0.2020	0.1646
06/15/00	Well 3	0.1759	0.0051	no data	no data	no data	no data
06/22/00	Well 3	0.1354	0.0049	0.2683	0.0184	0.1678	0.1391
06/29/00	Well 3	0.1205	0.0051	no data	no data	no data	no data
07/06/00	Well 3	0.1117	0.0048	0.2515	0.0169	0.1498	0.1238
07/13/00	Well 3	0.1233	0.0051	no data	no data	no data	no data
07/20/00	Well 3	0.1147	0.0052	0.2415	0.0160	0.1380	0.1057
07/27/00	Well 3	0.0944	0.0049	no data	no data	no data	no data
08/03/00	Well 3	0.1182	0.0052	0.2564	0.0186	0.1506	0.1218
08/10/00	Well 3	0.0953	0.0047	no data	no data	no data	no data
08/17/00	Well 3	0.1039	0.0050	0.2358	0.0170	0.1368	0.1047
08/24/00	Well 3	0.0871	0.0048	no data	no data	no data	no data
08/31/00	Well 3	0.0985	0.0048	0.2299	0.0167	0.1322	0.1018
09/07/00	Well 3	0.1243	0.0050	no data	no data	no data	no data
09/14/00	Well 3	0.1188	0.0049	0.2509	0.0178	0.1456	0.1120
09/21/00	Well 3	0.1309	0.0051	no data	no data	no data	no data
09/28/00	Well 3	0.1389	0.0052	0.2653	0.0190	0.1624	0.1260
10/05/00	Well 3	0.1428	0.0049	no data	no data	no data	no data
10/12/00	Well 3	0.1384	0.0049	0.2633	0.0195	0.1609	0.1255
10/19/00	Well 3	0.1467	0.0050	no data	no data	no data	no data

Date	Location	Cl	SO_4	Na	K	Mg	Ca
10/26/00	Well 3	0.1405	0.0056	0.2703	0.0205	0.1615	0.1291
11/02/00	Well 3	0.1081	0.0049	no data	no data	no data	no data
11/09/00	Well 3	0.1047	0.0050	0.2482	0.0183	0.1417	0.1154
11/16/00	Well 3	0.1149	0.0049	no data	no data	no data	no data
11/23/00	Well 3	0.1047	0.0049	0.2421	0.0178	0.1392	0.1186
11/30/00	Well 3	0.1148	0.0051	no data	no data	no data	no data
12/07/00	Well 3	0.1264	0.0050	0.2647	0.0194	0.1554	0.1285
12/14/00	Well 3	0.1198	0.0049	no data	no data	no data	no data
12/21/00	Well 3	0.1240	0.0047	0.2579	0.0183	0.1557	0.1284
12/28/00	Well 3	0.1225	0.0050	no data	no data	no data	no data
01/04/01	Well 3	0.0994	0.0050	0.2419	0.0183	0.1420	0.1203
01/11/01	Well 3	0.1029	0.0048	no data	no data	no data	no data
01/18/01	Well 3	0.1188	0.0050	0.2571	0.0187	0.1549	0.1291
01/25/01	Well 3	0.1193	0.0045	no data	no data	no data	no data
02/01/01	Well 3	0.1170	0.0044	0.2421	0.0181	0.1556	0.1250
02/08/01	Well 3	0.1218	0.0045	no data	no data	no data	no data
02/15/01	Well 3	0.1305	0.0046	0.2509	0.0194	0.1681	0.1351
03/01/01	Well 3	0.0611	0.0000	0.2660	0.0203	0.1806	0.1442
03/15/01	Well 3	0.1595	0.0047	0.2771	0.0206	0.1901	0.1546
03/29/01	Well 3	0.1775	0.0047	0.2891	0.0215	0.2023	0.1612
04/12/01	Well 3	0.1944	0.0048	0.3022	0.0231	0.2144	0.1716
04/26/01	Well 3	0.2029	0.0048	0.3068	0.0228	0.2168	0.1733
05/10/01	Well 3	0.2101	0.0052	0.2989	0.0232	0.2191	0.1614
05/24/01	Well 3	0.2089	0.0049	0.3127	0.0236	0.2262	0.1792
06/07/01	Well 3	0.2072	0.0048	0.3314	0.0242	0.2241	0.1623
06/21/01	Well 3	0.2061	0.0050	0.3199	0.0234	0.2186	0.1782
07/05/01	Well 3	0.1216	0.0049	0.2603	0.0188	0.1579	0.1332
07/19/01	Well 3	0.1212	0.0045	0.2462	0.0170	0.1514	0.1269
08/02/01	Well 3	0.1477	0.0046	0.2685	0.0194	0.1727	0.1406
08/16/01	Well 3	0.1307	0.0043	0.2519	0.0165	0.1595	0.1321
08/30/01	Well 3	0.1452	0.0045	0.2719	0.0191	0.1744	0.1425
09/13/01	Well 3	0.1353	0.0044	0.2637	0.0186	0.1617	0.2146
09/27/01	Well 3	0.0072	0.0000	0.0890	0.0078	0.0548	0.0420
10/11/01	Well 3	0.1264	0.0043	0.2548	0.0191	0.1584	0.1282
10/25/01	Well 3	0.1297	0.0045	0.2579	0.0187	0.1610	0.1275
11/08/01	Well 3	0.0573	0.0029	0.2056	0.0066	0.1227	0.1146
11/22/01	Well 3	0.0492	0.0039	0.1641	0.0025	0.0947	0.1024
12/08/01	Well 3	0.0645	0.0031	0.1242	0.0071	0.0732	0.0627
12/20/01	Well 3	0.0595	0.0031	0.2006	0.0116	0.1182	0.1035
01/03/02	Well 3	0.0760	0.0032	0.2183	0.0156	0.1351	0.1104
01/17/02	Well 3	0.0864	0.0032	0.2263	0.0166	0.1431	0.1190
01/31/02	Well 3	0.0960	0.0032	0.2374	0.0174	0.1528	0.1248
02/14/02	Well 3	0.1026	0.0031	0.2460	0.0186	0.1615	0.1342
02/28/02	Well 3	0.1847	0.0071	0.0740	0.0048	0.0459	0.0319

Date	Location	Cl	SO_4	Na	K	Mg	Ca
03/14/02	Well 3	0.1802	0.0076	0.2683	0.0184	0.1838	0.1520
03/28/02	Well 3	0.2075	0.0082	0.2817	0.0199	0.1930	0.1582
04/11/02	Well 3	0.2215	0.0076	0.2928	0.0229	0.1955	0.1556
04/25/02	Well 3	0.2245	0.0075	0.2864	0.0229	0.1985	0.1595
05/09/02	Well 3	0.0891	0.0076	0.1599	0.0061	0.0882	0.1001
05/23/02	Well 3	no data	no data	0.2642	0.0217	0.1628	0.1292
06/06/02	Well 3	no data	no data	0.2548	0.0205	0.1586	0.1311
06/20/02	Well 3	no data	no data	0.0033	0.0000	0.0025	0.0087
07/04/02	Well 3	no data	no data	0.2321	0.0171	0.1331	0.1070
07/19/02	Well 3	no data	no data	0.2196	0.0158	0.1259	0.1050
08/01/02	Well 3	no data	no data	0.2298	0.0168	0.1316	0.1176
08/15/02	Well 3	no data	no data	0.2057	0.0142	0.1204	0.1067
08/29/02	Well 3	no data	no data	0.2021	0.0136	0.1149	0.1018
09/12/02	Well 3	no data	no data	0.2305	0.0173	0.1383	0.1157
09/26/02	Well 3	no data	no data	0.2282	0.0164	0.1368	0.1244
02/06/00	Well 4	0.0681	0.0043	0.0433	0.0025	0.0074	0.0040
02/14/00	Well 4	0.0712	0.0046	0.0671	0.0027	0.0103	0.0116
02/21/00	Well 4	0.0160	0.0038	no data	no data	no data	no data
02/28/00	Well 4	0.0612	0.0023	0.0853	0.0032	0.0125	0.0327
03/06/00	Well 4	0.0600	0.0020	no data	no data	no data	no data
03/13/00	Well 4	0.0530	0.0020	0.0548	0.0029	0.0095	0.0076
03/23/00	Well 4	0.0595	0.0020	no data	no data	no data	no data
03/30/00	Well 4	0.0594	0.0019	0.0565	0.0029	0.0103	0.0080
04/06/00	Well 4	0.0593	0.0018	no data	no data	no data	no data
04/13/00	Well 4	0.0667	0.0034	0.0577	0.0030	0.0098	0.0070
04/20/00	Well 4	0.0588	0.0020	no data	no data	no data	no data
04/27/00	Well 4	0.0587	0.0019	0.0582	0.0029	0.0108	0.0082
05/04/00	Well 4	0.0567	0.0020	no data	no data	no data	no data
05/11/00	Well 4	0.0601	0.0020	0.0580	0.0028	0.0101	0.0085
05/18/00	Well 4	0.0554	0.0020	no data	no data	no data	no data
05/25/00	Well 4	0.0569	0.0020	0.0547	0.0034	0.0104	0.1157
06/01/00	Well 4	0.0547	0.0020	no data	no data	no data	no data
06/08/00	Well 4	0.0547	0.0019	0.0483	0.0028	0.0100	0.0063
06/15/00	Well 4	0.0578	0.0020	no data	no data	no data	no data
06/22/00	Well 4	0.0587	0.0020	0.0571	0.0030	0.0098	0.0051
06/29/00	Well 4	0.0602	0.0020	no data	no data	no data	no data
07/06/00	Well 4	0.0598	0.0021	0.0571	0.0023	0.0111	0.0059
07/13/00	Well 4	0.0594	0.0019	no data	no data	no data	no data
07/20/00	Well 4	0.0601	0.0020	0.0535	0.0025	0.0103	0.0000
07/27/00	Well 4	0.0612	0.0022	no data	no data	no data	no data
08/03/00	Well 4	0.0601	0.0019	0.0582	0.0025	0.0106	0.0054
08/10/00	Well 4	0.0572	0.0020	no data	no data	no data	no data
08/17/00	Well 4	0.0582	0.0021	0.0591	0.0026	0.0103	0.0051

Date	Location	Cl	SO_4	Na	K	Mg	Ca
08/24/00	Well 4	0.0594	0.0020	no data	no data	no data	no data
08/31/00	Well 4	0.0584	0.0020	0.0486	0.0000	0.0102	0.0050
09/07/00	Well 4	0.0623	0.0020	no data	no data	no data	no data
09/14/00	Well 4	0.0611	0.0021	0.0566	0.0000	0.0099	0.0050
09/21/00	Well 4	0.0623	0.0021	no data	no data	no data	no data
09/28/00	Well 4	0.0627	0.0021	0.0547	0.0029	0.0106	0.0057
10/05/00	Well 4	0.0642	0.0022	no data	no data	no data	no data
10/12/00	Well 4	0.0612	0.0021	0.0568	0.0027	0.0104	0.0050
10/19/00	Well 4	0.0618	0.0021	no data	no data	no data	no data
10/26/00	Well 4	0.0620	0.0021	0.0549	0.0029	0.0100	0.0068
11/02/00	Well 4	0.0613	0.0021	no data	no data	no data	no data
11/09/00	Well 4	0.0612	0.0021	0.0561	0.0034	0.0098	0.0000
11/16/00	Well 4	0.0608	0.0021	no data	no data	no data	no data
11/23/00	Well 4	0.0596	0.0021	0.0706	0.0087	0.0105	0.0072
11/30/00	Well 4	0.0604	0.0020	no data	no data	no data	no data
12/07/00	Well 4	0.0624	0.0022	0.0574	0.0031	0.0104	0.0085
12/14/00	Well 4	0.0619	0.0022	no data	no data	no data	no data
12/21/00	Well 4	0.0616	0.0023	0.0490	0.0000	0.0104	0.0072
12/28/00	Well 4	0.0617	0.0022	no data	no data	no data	no data
01/04/01	Well 4	0.0611	0.0022	0.0566	0.0000	0.0110	0.0075
01/11/01	Well 4	0.0595	0.0022	no data	no data	no data	no data
01/18/01	Well 4	0.0624	0.0022	0.0605	0.0036	0.0109	0.0076
01/25/01	Well 4	0.0592	0.0000	no data	no data	no data	no data
02/01/01	Well 4	0.0604	0.0000	0.0493	0.0015	0.0103	0.0039
02/08/01	Well 4	0.0598	0.0000	no data	no data	no data	no data
02/15/01	Well 4	0.0609	0.0000	0.0494	0.0015	0.0102	0.0043
03/01/01	Well 4	0.1468	0.0046	0.0530	0.0018	0.0108	0.0053
03/15/01	Well 4	0.0609	0.0000	0.0512	0.0020	0.0102	0.0054
03/29/01	Well 4	0.0625	0.0000	0.0514	0.0000	0.0107	0.0051
04/12/01	Well 4	0.0662	0.0017	0.0565	0.0017	0.0116	0.0068
04/26/01	Well 4	0.0626	0.0018	0.0595	0.0039	0.0108	0.0056
05/10/01	Well 4	0.0603	0.0000	0.0544	0.0031	0.0111	0.0073
05/24/01	Well 4	0.0580	0.0000	0.0510	0.0019	0.0104	0.0062
06/07/01	Well 4	0.0603	0.0017	0.0582	0.0037	0.0113	0.0073
06/21/01	Well 4	0.0603	0.0016	0.0512	0.0013	0.0098	0.0041
07/06/01	Well 4	0.0594	0.0016	0.0514	0.0000	0.0101	0.0043
07/19/01	Well 4	0.0602	0.0000	0.0485	0.0000	0.0097	0.0032
08/02/01	Well 4	0.0606	0.0000	0.0502	0.0000	0.0089	0.0024
08/16/01	Well 4	0.0582	0.0000	0.0498	0.0011	0.0088	0.0031
08/30/01	Well 4	0.0596	0.0000	0.0565	0.0011	0.0087	0.0040
09/13/01	Well 4	0.0609	0.0018	0.0520	0.0011	0.0087	0.0034
09/27/01	Well 4	0.0160	0.0000	0.0134	0.0027	0.0026	0.0000
10/11/01	Well 4	0.0581	0.0000	0.0493	0.0000	0.0078	0.0016
10/25/01	Well 4	0.0624	0.0016	0.0565	0.0020	0.0081	0.0019

Date	Location	Cl	SO_4	Na	K	Mg	Ca
11/08/01	Well 4	0.0584	0.0016	0.0530	0.0012	0.0082	0.0016
11/22/01	Well 4	0.0578	0.0000	0.0483	0.0000	0.0083	0.0012
12/08/01	Well 4	0.0428	0.0000	0.0113	0.0000	0.0000	0.0001
12/20/01	Well 4	0.0427	0.0000	0.0203	0.0011	0.0033	0.0000
01/03/02	Well 4	0.0426	0.0000	0.0518	0.0011	0.0088	0.0015
01/17/02	Well 4	0.0426	0.0000	0.0494	0.0012	0.0082	0.0008
01/31/02	Well 4	0.0450	0.0000	0.0497	0.0014	0.0097	0.0041
02/14/02	Well 4	0.0456	0.0000	0.0517	0.0013	0.0090	0.0012
02/28/02	Well 4	0.0678	0.0000	0.0552	0.0026	0.0090	0.0014
03/14/02	Well 4	0.0814	0.0000	0.0502	0.0015	0.0088	0.0017
03/28/02	Well 4	0.0921	0.0000	0.0496	0.0000	0.0087	0.0013
04/11/02	Well 4	0.0840	0.0000	0.0506	0.0000	0.0090	0.0000
04/25/02	Well 4	0.0909	0.0000	0.0534	0.0052	0.0102	0.0077
05/09/02	Well 4	0.0838	0.0000	0.0503	0.0000	0.0100	0.0069
05/23/02	Well 4	0.0607	0.0000	0.0487	0.0000	0.0093	0.0064
06/06/02	Well 4	0.0582	0.0000	0.0496	0.0000	0.0088	0.0000
06/20/02	Well 4	0.0564	0.0000	0.0551	0.0063	0.0024	0.0040
07/04/02	Well 4	0.0596	0.0000	0.0509	0.0000	0.0089	0.0000
07/19/02	Well 4	0.0613	0.0000	0.0537	0.0000	0.0081	0.0000
08/01/02	Well 4	0.0625	0.0000	0.0517	0.0000	0.0084	0.0064
08/15/02	Well 4	0.0585	0.0000	0.0545	0.0000	0.0085	0.0062
08/29/02	Well 4	0.0566	0.0000	0.0519	0.0000	0.0092	0.0065
09/12/02	Well 4	0.0576	0.0000	0.0514	0.0000	0.0082	0.0000
09/26/02	Well 4	0.0606	0.0000	0.0514	0.0000	0.0089	0.0064
02/06/00	Well 5	0.0630	0.0000	0.0500	0.0026	0.0041	0.0000
02/14/00	Well 5	0.1039	0.0029	0.0673	0.0037	0.0122	0.0091
02/21/00	Well 5	0.0500	0.0045	no data	no data	no data	no data
02/28/00	Well 5	0.1010	0.0000	0.0691	0.0036	0.0125	0.0082
03/06/00	Well 5	0.0916	0.0000	no data	no data	no data	no data
03/13/00	Well 5	0.0932	0.0000	0.0736	0.0039	0.0151	0.0112
03/23/00	Well 5	0.0985	0.0019	no data	no data	no data	no data
03/30/00	Well 5	0.0942	0.0018	0.0644	0.0038	0.0159	0.0114
04/06/00	Well 5	0.0898	0.0018	no data	no data	no data	no data
04/13/00	Well 5	0.0904	0.0026	0.0623	0.0033	0.0116	0.0081
04/20/00	Well 5	0.0832	0.0019	no data	no data	no data	no data
04/27/00	Well 5	0.0892	0.0020	0.0666	0.0032	0.0120	0.0088
05/04/00	Well 5	0.0827	0.0018	no data	no data	no data	no data
05/11/00	Well 5	0.0882	0.0019	0.0682	0.0033	0.0120	0.0082
05/18/00	Well 5	0.0860	0.0019	no data	no data	no data	no data
05/25/00	Well 5	0.0895	0.0018	0.0648	0.0030	0.0119	0.0062
06/01/00	Well 5	0.0882	0.0018	no data	no data	no data	no data
06/08/00	Well 5	0.0895	0.0018	0.0665	0.0030	0.0112	0.0063
06/15/00	Well 5	0.0841	0.0000	no data	no data	no data	no data

Date	Location	Cl	SO_4	Na	K	Mg	Ca
06/22/00	Well 5	0.0954	0.0000	0.0666	0.0029	0.0100	0.0050
06/29/00	Well 5	0.0888	0.0018	no data	no data	no data	no data
07/06/00	Well 5	0.0914	0.0017	0.0703	0.0029	0.0099	0.0051
07/13/00	Well 5	0.0917	0.0018	no data	no data	no data	no data
07/20/00	Well 5	0.0912	0.0018	0.0617	0.0028	0.0101	0.0044
07/27/00	Well 5	0.0938	0.0018	no data	no data	no data	no data
08/03/00	Well 5	0.0898	0.0000	0.0636	0.0034	0.0143	0.0094
08/10/00	Well 5	0.0945	0.0000	no data	no data	no data	no data
08/17/00	Well 5	0.0986	0.0018	0.0654	0.0032	0.0099	0.0041
08/24/00	Well 5	0.0941	0.0000	no data	no data	no data	no data
08/31/00	Well 5	0.0918	0.0017	0.0707	0.0031	0.0110	0.0053
09/07/00	Well 5	0.0921	0.0000	no data	no data	no data	no data
09/14/00	Well 5	0.0890	0.0018	0.0631	0.0029	0.0100	0.0048
09/21/00	Well 5	0.0885	0.0020	no data	no data	no data	no data
09/28/00	Well 5	0.0894	0.0018	0.0617	0.0028	0.0089	0.0036
10/05/00	Well 5	0.0888	0.0020	no data	no data	no data	no data
10/12/00	Well 5	0.0915	0.0019	0.0623	0.0029	0.0101	0.0052
10/19/00	Well 5	0.0939	0.0019	no data	no data	no data	no data
10/26/00	Well 5	0.0898	0.0018	0.0666	0.0054	0.0097	0.0066
11/02/00	Well 5	0.0929	0.0018	no data	no data	no data	no data
11/09/00	Well 5	0.1061	0.0024	0.0650	0.0033	0.0090	0.0000
11/16/00	Well 5	0.0879	0.0019	no data	no data	no data	no data
11/23/00	Well 5	0.0915	0.0019	0.0779	0.0120	0.0097	0.0065
11/30/00	Well 5	0.0877	0.0021	no data	no data	no data	no data
12/07/00	Well 5	0.0896	0.0019	0.0649	0.0030	0.0122	0.0103
12/14/00	Well 5	0.0946	0.0019	no data	no data	no data	no data
12/21/00	Well 5	0.0860	0.0019	0.0587	0.0031	0.0101	0.0061
12/28/00	Well 5	0.0896	0.0018	no data	no data	no data	no data
01/04/01	Well 5	0.0902	0.0019	0.0628	0.0025	0.0093	0.0059
01/11/01	Well 5	0.0899	0.0020	no data	no data	no data	no data
01/18/01	Well 5	0.0851	0.0019	0.0576	0.0031	0.0104	0.0072
01/25/01	Well 5	0.0804	0.0000	no data	no data	no data	no data
02/01/01	Well 5	0.0855	0.0017	0.0536	0.0018	0.0101	0.0048
02/08/01	Well 5	0.0826	0.0000	no data	no data	no data	no data
02/15/01	Well 5	0.0842	0.0000	0.0543	0.0017	0.0100	0.0039
03/01/01	Well 5	0.5208	0.0158	0.0536	0.0021	0.0106	0.0057
03/15/01	Well 5	0.0772	0.0000	0.0526	0.0019	0.0101	0.0058
03/29/01	Well 5	0.0814	0.0000	0.0536	0.0015	0.0088	0.0044
04/12/01	Well 5	0.0808	0.0000	0.0544	0.0014	0.0087	0.0035
04/26/01	Well 5	0.0868	0.0018	0.0580	0.0018	0.0092	0.0056
05/10/01	Well 5	0.0827	0.0000	0.0575	0.0017	0.0094	0.0054
05/24/01	Well 5	0.0833	0.0000	0.0545	0.0016	0.0089	0.0048
06/07/01	Well 5	0.0914	0.0000	0.0731	0.0047	0.0079	0.0017
06/21/01	Well 5	0.0990	0.0000	0.0592	0.0000	0.0060	0.0017

Date	Location	Cl	SO_4	Na	K	Mg	Ca
07/06/01	Well 5	0.0912	0.0000	0.0579	0.0000	0.0062	0.0015
07/19/01	Well 5	0.0902	0.0000	0.0570	0.0011	0.0065	0.0019
08/02/01	Well 5	0.0815	0.0000	0.0549	0.0000	0.0071	0.0023
08/16/01	Well 5	0.0923	0.0000	0.0118	0.0000	0.0022	0.0000
08/30/01	Well 5	0.0904	0.0000	0.0677	0.0014	0.0077	0.0032
09/13/01	Well 5	0.0826	0.0021	0.0586	0.0011	0.0077	0.0028
09/27/01	Well 5	0.0360	0.0000	-0.0005	0.0000	0.0012	0.0000
10/11/01	Well 5	0.0856	0.0000	0.0559	0.0015	0.0077	0.0040
10/25/01	Well 5	0.0867	0.0000	0.0598	0.0021	0.0079	0.0010
11/08/01	Well 5	0.0846	0.0020	0.0587	0.0011	0.0064	0.0011
11/22/01	Well 5	0.0859	0.0000	0.0556	0.0011	0.0064	0.0000
12/08/01	Well 5	0.0271	0.0000	0.0458	0.0000	0.0050	0.0000
12/20/01	Well 5	0.0680	0.0000	0.0576	0.0000	0.0090	0.0012
01/03/02	Well 5	0.0712	0.0000	0.0607	0.0017	0.0089	0.0013
01/17/02	Well 5	0.0653	0.0000	0.0561	0.0011	0.0089	0.0008
01/31/02	Well 5	0.0681	0.0000	0.0577	0.0015	0.0090	0.0005
02/14/02	Well 5	0.0638	0.0000	0.0611	0.0019	0.0102	0.0018
02/28/02	Well 5	0.1136	0.0000	0.0578	0.0015	0.0085	0.0016
03/14/02	Well 5	0.1124	0.0000	0.0627	0.0043	0.0121	0.0041
03/28/02	Well 5	0.1069	0.0000	0.0578	0.0019	0.0090	0.0019
04/11/02	Well 5	0.1034	0.0000	0.0436	0.0000	0.0098	0.0086
04/25/02	Well 5	0.1158	0.0000	0.0577	0.0056	0.0089	0.0077
05/09/02	Well 5	0.1174	0.0000	0.0566	0.0000	0.0077	0.0061
05/23/02	Well 5	0.0836	0.0000	0.0588	0.0000	0.0079	0.0056
06/06/02	Well 5	0.0876	0.0000	0.0560	0.0000	0.0048	0.0050
06/20/02	Well 5	0.0862	0.0000	0.0629	0.0103	0.0026	0.0063
07/04/02	Well 5	0.0879	0.0000	0.0598	0.0054	0.0119	0.0105
07/19/02	Well 5	0.0923	0.0000	0.0660	0.0066	0.0089	0.0067
08/01/02	Well 5	0.0926	0.0000	0.0600	0.0000	0.0084	0.0064
08/15/02	Well 5	0.0869	0.0000	0.0591	0.0000	0.0078	0.0068
08/29/02	Well 5	0.0928	0.0000	0.0597	0.0000	0.0090	0.0063
09/12/02	Well 5	0.0940	0.0000	0.0584	0.0000	0.0102	0.0069
09/26/02	Well 5	0.0964	0.0000	0.0619	0.0058	0.0130	0.0108
02/06/00	Well 6	0.0516	0.0026	0.1105	0.0000	0.0084	0.0027
02/14/00	Well 6	0.0673	0.0030	0.1184	0.0025	0.0107	0.0081
02/21/00	Well 6	0.0285	0.0051	no data	no data	no data	no data
02/28/00	Well 6	0.0673	0.0033	0.1542	0.0032	0.0137	0.0389
03/06/00	Well 6	0.0606	0.0032	no data	no data	no data	no data
03/16/00	Well 6	0.0632	0.0034	0.1118	0.0024	0.0136	0.0096
03/23/00	Well 6	0.0525	0.0031	no data	no data	no data	no data
03/30/00	Well 6	0.0506	0.0028	0.1105	0.0029	0.0154	0.0115
04/06/00	Well 6	0.0548	0.0034	no data	no data	no data	no data
04/13/00	Well 6	0.0543	0.0033	0.1083	0.0030	0.0133	0.0111

Date	Location	Cl	SO_4	Na	K	Mg	Ca
04/20/00	Well 6	0.0535	0.0031	no data	no data	no data	no data
04/27/00	Well 6	0.0542	0.0031	0.1047	0.0029	0.0140	0.0118
05/04/00	Well 6	0.0515	0.0031	no data	no data	no data	no data
05/11/00	Well 6	0.0517	0.0029	0.1008	0.0029	0.0155	0.0131
05/18/00	Well 6	0.0504	0.0029	no data	no data	no data	no data
05/25/00	Well 6	0.0519	0.0030	0.1019	0.0031	0.0146	0.0110
06/01/00	Well 6	0.0514	0.0030	no data	no data	no data	no data
06/08/00	Well 6	0.0538	0.0031	0.1083	0.0000	0.0127	0.0083
06/15/00	Well 6	0.0581	0.0032	no data	no data	no data	no data
06/22/00	Well 6	0.0504	0.0027	0.1129	0.0000	0.0106	0.0061
06/29/00	Well 6	0.0653	0.0031	no data	no data	no data	no data
07/06/00	Well 6	0.0670	0.0031	0.1127	0.0000	0.0103	0.0051
07/13/00	Well 6	0.0674	0.0032	no data	no data	no data	no data
07/20/00	Well 6	0.0676	0.0031	0.1149	0.0000	0.0104	0.0054
07/27/00	Well 6	0.0682	0.0030	no data	no data	no data	no data
08/03/00	Well 6	0.0684	0.0032	0.1172	0.0000	0.0100	0.0056
08/10/00	Well 6	0.0671	0.0030	no data	no data	no data	no data
08/17/00	Well 6	0.0669	0.0031	0.1175	0.0000	0.0099	0.0046
08/24/00	Well 6	0.0662	0.0031	no data	no data	no data	no data
08/31/00	Well 6	0.0669	0.0032	0.1186	0.0000	0.0100	0.0052
09/07/00	Well 6	0.0665	0.0033	no data	no data	no data	no data
09/14/00	Well 6	0.0642	0.0032	0.1171	0.0028	0.0104	0.0053
09/21/00	Well 6	0.0637	0.0035	no data	no data	no data	no data
09/28/00	Well 6	0.0631	0.0034	0.1172	0.0000	0.0121	0.0061
10/05/00	Well 6	0.0605	0.0035	no data	no data	no data	no data
10/12/00	Well 6	0.0641	0.0034	0.1126	0.0028	0.0121	0.0069
10/19/00	Well 6	0.0613	0.0033	no data	no data	no data	no data
10/26/00	Well 6	0.0613	0.0033	0.1123	0.0026	0.0115	0.0068
11/02/00	Well 6	0.0662	0.0032	no data	no data	no data	no data
11/09/00	Well 6	0.0678	0.0034	0.1188	0.0031	0.0105	0.0076
11/16/00	Well 6	0.0628	0.0032	no data	no data	no data	no data
11/23/00	Well 6	0.0647	0.0032	0.1330	0.0000	0.0112	0.0080
11/30/00	Well 6	0.0659	0.0034	no data	no data	no data	no data
12/07/00	Well 6	0.0630	0.0036	0.1206	0.0000	0.0116	0.0078
12/14/00	Well 6	0.0630	0.0035	no data	no data	no data	no data
12/21/00	Well 6	0.0607	0.0034	0.1116	0.0000	0.0114	0.0071
12/28/00	Well 6	0.0648	0.0036	no data	no data	no data	no data
01/04/01	Well 6	0.0664	0.0033	0.1228	0.0000	0.0104	0.0068
01/11/01	Well 6	0.0618	0.0032	no data	no data	no data	no data
01/18/01	Well 6	0.0637	0.0035	0.1194	0.0000	0.0106	0.0077
01/25/01	Well 6	0.0607	0.0028	no data	no data	no data	no data
02/01/01	Well 6	0.0629	0.0030	0.1143	0.0015	0.0117	0.0059
02/08/01	Well 6	0.0601	0.0030	no data	no data	no data	no data
02/15/01	Well 6	0.0577	0.0030	0.1021	0.0011	0.0119	0.0062

Date	Location	Cl	SO_4	Na	K	Mg	Ca
03/01/01	Well 6	0.4735	0.0147	0.0994	0.0013	0.0127	0.0088
03/15/01	Well 6	0.0525	0.0028	0.0929	0.0011	0.0138	0.0089
03/29/01	Well 6	0.0530	0.0028	0.0917	0.0000	0.0133	0.0077
04/12/01	Well 6	0.0543	0.0027	0.0900	0.0011	0.0139	0.0091
04/26/01	Well 6	0.0568	0.0037	0.1022	0.0016	0.0132	0.0088
05/10/01	Well 6	0.0534	0.0030	0.0078	0.0000	0.0033	0.0019
05/24/01	Well 6	0.0521	0.0027	0.0932	0.0018	0.0142	0.0099
06/07/01	Well 6	0.0512	0.0027	0.0975	0.0000	0.0111	0.0066
06/21/01	Well 6	0.0545	0.0029	0.0993	0.0000	0.0108	0.0039
07/05/01	Well 6	0.0628	0.0026	0.1042	0.0000	0.0084	0.0025
07/19/01	Well 6	0.0623	0.0025	0.1077	0.0000	0.0084	0.0029
08/02/01	Well 6	0.0594	0.0026	0.1042	0.0000	0.0094	0.0039
08/16/01	Well 6	0.0600	0.0028	0.1135	0.0000	0.0100	0.0036
08/30/01	Well 6	0.0601	0.0025	0.1128	0.0000	0.0099	0.0029
09/13/01	Well 6	0.0646	0.0036	0.1115	0.0000	0.0102	0.0047
09/27/01	Well 6	0.0555	0.0026	0.0082	0.0000	0.0021	0.0000
10/11/01	Well 6	0.0679	0.0027	0.1154	0.0000	0.0084	0.0018
10/25/01	Well 6	0.0095	0.0000	0.1136	0.0000	0.0099	0.0025
11/08/01	Well 6	0.0688	0.0023	0.1231	0.0000	0.0103	0.0019
11/22/01	Well 6	0.0747	0.0021	0.1286	0.0000	0.0101	0.0008
12/08/01	Well 6	0.0410	0.0000	0.1277	0.0000	0.0097	0.0007
12/20/01	Well 6	0.0227	0.0000	0.0428	0.0000	0.0040	0.0000
01/03/02	Well 6	0.0518	0.0021	0.1231	0.0000	0.0095	0.0014
01/17/02	Well 6	0.0474	0.0021	0.1232	0.0000	0.0111	0.0018
01/31/02	Well 6	0.0478	0.0028	0.1198	0.0000	0.0119	0.0026
02/14/02	Well 6	0.0444	0.0019	0.1210	0.0000	0.0123	0.0030
02/28/02	Well 6	0.0688	0.0067	0.1180	0.0013	0.0121	0.0034
03/14/02	Well 6	0.0833	0.0066	0.1113	0.0017	0.0116	0.0036
03/28/02	Well 6	0.0858	0.0063	0.1106	0.0000	0.0124	0.0043
04/11/02	Well 6	0.0920	0.0000	0.1025	0.0000	0.0139	0.0115
04/25/02	Well 6	0.0908	0.0065	0.1108	0.0067	0.0134	0.0117
05/09/02	Well 6	0.0913	0.0000	0.1157	0.0000	0.0090	0.0058
05/23/02	Well 6	0.0679	0.0033	0.1146	0.0000	0.0092	0.0062
06/06/02	Well 6	0.0707	0.0037	0.1216	0.0000	0.0026	0.0092
06/20/02	Well 6	0.0660	0.0034	0.1356	0.0068	0.0029	0.0053
07/04/02	Well 6	0.0750	0.0030	0.1362	0.0000	0.0095	0.0062
07/19/02	Well 6	0.0750	0.0032	0.1325	0.0000	0.0104	0.0064
08/01/02	Well 6	0.0768	0.0032	0.1331	0.0000	0.0097	0.0058
08/15/02	Well 6	0.0789	0.0030	0.1457	0.0000	0.0111	0.0056
08/29/02	Well 6	0.0769	0.0000	0.1541	0.0000	0.0119	0.0000
09/12/02	Well 6	0.0682	0.0033	0.1327	0.0000	0.0107	0.0000
09/26/02	Well 6	0.0719	0.0032	0.1463	0.0000	0.0124	0.0072
02/06/00	Well 7	0.0501	0.0023	0.1072	0.0047	0.0202	0.0316

Date	Location	Cl	SO_4	Na	K	Mg	Ca
02/14/00	Well 7	0.0640	0.0063	0.0635	0.0024	0.0098	0.0140
02/21/00	Well 7	0.0195	0.0036	no data	no data	no data	no data
02/28/00	Well 7	0.0526	0.0032	0.0684	0.0028	0.0100	0.0138
03/06/00	Well 7	0.0516	0.0032	no data	no data	no data	no data
03/16/00	Well 7	0.0478	0.0032	0.0542	0.0029	0.0108	0.0145
03/23/00	Well 7	0.0425	0.0035	no data	no data	no data	no data
03/30/00	Well 7	0.0505	0.0033	0.0598	0.0027	0.0101	0.0145
04/06/00	Well 7	0.0512	0.0033	no data	no data	no data	no data
04/13/00	Well 7	0.0532	0.0031	0.0740	0.0034	0.0114	0.0157
04/20/00	Well 7	0.0576	0.0036	no data	no data	no data	no data
04/27/00	Well 7	0.0513	0.0035	0.0556	0.0033	0.0106	0.0140
05/04/00	Well 7	0.0468	0.0033	no data	no data	no data	no data
05/11/00	Well 7	0.0475	0.0033	0.0550	0.0026	0.0106	0.0167
05/18/00	Well 7	0.0489	0.0031	no data	no data	no data	no data
05/25/00	Well 7	0.0426	0.0037	0.0588	0.0027	0.0115	0.0184
06/01/00	Well 7	0.0407	0.0033	no data	no data	no data	no data
06/08/00	Well 7	0.0478	0.0033	0.0626	0.0024	0.0090	0.0107
06/15/00	Well 7	0.0518	0.0033	no data	no data	no data	no data
06/22/00	Well 7	0.0540	0.0031	0.0692	0.0024	0.0095	0.0114
06/29/00	Well 7	0.0511	0.0031	no data	no data	no data	no data
07/06/00	Well 7	0.0466	0.0030	0.0638	0.0028	0.0097	0.0111
07/13/00	Well 7	0.0518	0.0032	no data	no data	no data	no data
07/20/00	Well 7	0.0536	0.0032	0.0652	0.0000	0.0098	0.0112
07/27/00	Well 7	0.0546	0.0029	no data	no data	no data	no data
08/03/00	Well 7	0.0527	0.0032	0.0623	0.0024	0.0099	0.0115
08/10/00	Well 7	0.0599	0.0033	no data	no data	no data	no data
08/17/00	Well 7	0.0562	0.0032	0.0629	0.0036	0.0108	0.0110
08/24/00	Well 7	0.0565	0.0029	no data	no data	no data	no data
08/31/00	Well 7	0.0543	0.0031	0.0532	0.0000	0.0104	0.0106
09/07/00	Well 7	0.0553	0.0031	no data	no data	no data	no data
09/14/00	Well 7	0.0569	0.0032	0.0660	0.0031	0.0099	0.0106
09/21/00	Well 7	0.0575	0.0035	no data	no data	no data	no data
09/28/00	Well 7	0.0547	0.0034	0.0634	0.0025	0.0101	0.0106
10/05/00	Well 7	0.0612	0.0034	no data	no data	no data	no data
10/12/00	Well 7	0.0544	0.0034	0.0574	0.0024	0.0093	0.0134
10/19/00	Well 7	0.0542	0.0035	no data	no data	no data	no data
10/26/00	Well 7	0.0571	0.0031	0.0603	0.0025	0.0095	0.0122
11/02/00	Well 7	0.0549	0.0029	no data	no data	no data	no data
11/09/00	Well 7	0.0563	0.0035	0.0526	0.0000	0.0121	0.0160
11/16/00	Well 7	0.0524	0.0032	no data	no data	no data	no data
11/23/00	Well 7	0.0575	0.0033	0.0662	0.0029	0.0101	0.0131
11/30/00	Well 7	0.0539	0.0035	no data	no data	no data	no data
12/07/00	Well 7	0.0557	0.0033	0.0667	0.0030	0.0098	0.0134
12/14/00	Well 7	0.0558	0.0036	no data	no data	no data	no data

Date	Location	Cl	SO_4	Na	K	Mg	Ca
12/21/00	Well 7	0.0562	0.0033	0.0607	0.0025	0.0093	0.0108
12/28/00	Well 7	0.0569	0.0034	no data	no data	no data	no data
01/04/01	Well 7	0.0567	0.0030	0.0803	0.0030	0.0119	0.0152
01/11/01	Well 7	0.0503	0.0032	no data	no data	no data	no data
01/18/01	Well 7	0.0551	0.0034	0.0563	0.0027	0.0098	0.0132
01/25/01	Well 7	0.0570	0.0031	no data	no data	no data	no data
02/01/01	Well 7	0.0507	0.0028	0.0518	0.0018	0.0101	0.0116
02/08/01	Well 7	0.0492	0.0030	no data	no data	no data	no data
02/15/01	Well 7	0.0540	0.0028	0.0544	0.0018	0.0100	0.0121
03/01/01	Well 7	0.0537	0.0030	0.0476	0.0020	0.0091	0.0106
03/15/01	Well 7	0.0506	0.0029	0.0492	0.0013	0.0097	0.0110
03/29/01	Well 7	0.0516	0.0031	0.0541	0.0023	0.0135	0.0142
04/12/01	Well 7	0.0601	0.0029	0.0553	0.0018	0.0103	0.0125
04/26/01	Well 7	0.0492	0.0031	0.0486	0.0021	0.0103	0.0144
05/10/01	Well 7	0.0485	0.0027	0.0459	0.0022	0.0103	0.0144
05/24/01	Well 7	0.0543	0.0031	0.0494	0.0021	0.0102	0.0140
06/07/01	Well 7	0.0507	0.0036	0.0558	0.0016	0.0070	0.0117
06/21/01	Well 7	0.0540	0.0029	0.0547	0.0013	0.0089	0.0104
07/05/01	Well 7	0.0545	0.0024	0.0560	0.0011	0.0088	0.0099
07/19/01	Well 7	0.0581	0.0026	0.0670	0.0039	0.0128	0.0154
08/02/01	Well 7	0.0510	0.0027	0.0499	0.0012	0.0092	0.0098
08/16/01	Well 7	0.0676	0.0024	0.0867	0.0028	0.0153	0.0177
08/30/01	Well 7	0.0562	0.0028	0.0602	0.0012	0.0106	0.0163
09/13/01	Well 7	0.0517	0.0029	0.0526	0.0011	0.0087	0.0121
09/27/01	Well 7	0.0148	0.0000	0.0160	0.0000	0.0034	0.0024
10/11/01	Well 7	0.0579	0.0026	0.0583	0.0000	0.0084	0.0069
10/25/01	Well 7	0.0555	0.0028	0.0604	0.0015	0.0106	0.0134
11/08/01	Well 7	0.0648	0.0024	0.0942	0.0013	0.0159	0.0160
11/22/01	Well 7	0.0596	0.0019	0.0460	0.0000	0.0083	0.0087
12/08/01	Well 7	0.0409	0.0016	0.0564	0.0000	0.0088	0.0086
12/20/01	Well 7	0.0367	0.0020	0.0715	0.0000	0.0103	0.0090
01/03/02	Well 7	0.0387	0.0021	0.0555	0.0000	0.0083	0.0065
01/17/02	Well 7	0.0393	0.0019	0.0657	0.0013	0.0085	0.0064
01/31/02	Well 7	0.0405	0.0024	0.0523	0.0011	0.0080	0.0101
02/14/02	Well 7	0.0385	0.0023	0.0536	0.0000	0.0080	0.0064
02/28/02	Well 7	0.0642	0.0066	0.0529	0.0000	0.0088	0.0064
03/14/02	Well 7	0.0822	0.0066	0.0539	0.0016	0.0092	0.0077
03/28/02	Well 7	0.0799	0.0067	0.0526	0.0000	0.0091	0.0070
04/11/02	Well 7	0.0842	0.0067	0.0534	0.0000	0.0093	0.0132
04/25/02	Well 7	0.0831	0.0067	0.0597	0.0052	0.0108	0.0156
05/09/02	Well 7	0.0894	0.0065	0.0737	0.0000	0.0135	0.0174
05/23/02	Well 7	0.0534	0.0032	0.0583	0.0000	0.0103	0.0140
06/06/02	Well 7	0.0550	0.0034	0.0701	0.0066	0.0020	0.0043
06/20/02	Well 7	0.0543	0.0033	0.0000	0.0060	0.0017	0.0000

Date	Location	Cl	SO_4	Na	K	Mg	Ca
07/04/02	Well 7	0.0553	0.0031	0.0669	0.0000	0.0106	0.0129
07/19/02	Well 7	0.0561	0.0034	0.0615	0.0000	0.0127	0.0141
08/01/02	Well 7	0.0504	0.0030	0.0596	0.0055	0.0117	0.0148
08/15/02	Well 7	0.0143	0.0000	0.0640	0.0000	0.0112	0.0135
08/29/02	Well 7	0.0480	0.0030	0.0665	0.0000	0.0138	0.0172
09/12/02	Well 7	0.0505	0.0031	0.0572	0.0000	0.0115	0.0152
09/26/02	Well 7	0.0508	0.0030	0.0670	0.0056	0.0134	0.0163
02/06/00	Well 8	0.0529	0.0037	0.0802	0.0152	0.0100	0.0496
02/14/00	Well 8	0.0495	0.0030	0.0584	0.0189	0.0287	0.0413
02/21/00	Well 8	0.0202	0.0024	no data	no data	no data	no data
02/28/00	Well 8	0.0627	0.0034	0.0669	0.0205	0.0289	0.0390
03/06/00	Well 8	0.0622	0.0033	no data	no data	no data	no data
03/16/00	Well 8	0.0603	0.0031	0.0870	0.0243	0.0409	0.0524
03/23/00	Well 8	0.0601	0.0030	no data	no data	no data	no data
03/30/00	Well 8	0.0537	0.0026	0.0822	0.0237	0.0366	0.0495
04/06/00	Well 8	0.0635	0.0029	no data	no data	no data	no data
04/13/00	Well 8	0.0650	0.0034	0.0822	0.0231	0.0330	0.0461
04/20/00	Well 8	0.0614	0.0029	no data	no data	no data	no data
04/27/00	Well 8	0.0710	0.0035	0.0848	0.0237	0.0343	0.0476
05/04/00	Well 8	0.0705	0.0031	no data	no data	no data	no data
05/11/00	Well 8	0.0835	0.0042	0.0833	0.0255	0.0352	0.0495
05/18/00	Well 8	0.0748	0.0038	no data	no data	no data	no data
05/25/00	Well 8	0.0685	0.0036	0.0843	0.0236	0.0319	0.0421
06/01/00	Well 8	0.0641	0.0034	no data	no data	no data	no data
06/08/00	Well 8	0.0636	0.0044	0.0710	0.0231	0.0254	0.0309
06/15/00	Well 8	0.0700	0.0034	no data	no data	no data	no data
06/22/00	Well 8	0.0593	0.0036	0.0426	0.0165	0.0167	0.0201
06/29/00	Well 8	0.0719	0.0038	no data	no data	no data	no data
07/06/00	Well 8	0.0609	0.0038	0.0579	0.0182	0.0216	0.0266
07/13/00	Well 8	0.0679	0.0037	no data	no data	no data	no data
07/20/00	Well 8	0.0645	0.0036	0.0597	0.0186	0.0241	0.0289
07/27/00	Well 8	0.0609	0.0034	no data	no data	no data	no data
08/03/00	Well 8	0.0626	0.0036	0.0638	0.0187	0.0259	0.0318
08/10/00	Well 8	0.0597	0.0033	no data	no data	no data	no data
08/17/00	Well 8	0.0608	0.0034	0.0537	0.0168	0.0214	0.0252
08/24/00	Well 8	0.0602	0.0039	no data	no data	no data	no data
08/31/00	Well 8	0.0609	0.0038	0.0569	0.0188	0.0245	0.0294
09/07/00	Well 8	0.0613	0.0038	no data	no data	no data	no data
09/14/00	Well 8	0.0661	0.0037	0.0650	0.0197	0.0273	0.0316
09/21/00	Well 8	0.0624	0.0030	no data	no data	no data	no data
09/28/00	Well 8	0.0629	0.0033	0.0730	0.0211	0.0298	0.0368
10/05/00	Well 8	0.0622	0.0032	no data	no data	no data	no data
10/12/00	Well 8	0.0612	0.0041	0.0620	0.0191	0.0222	0.0292

Date	Location	Cl	SO_4	Na	K	Mg	Ca
10/19/00	Well 8	0.0416	0.0052	no data	no data	no data	no data
10/26/00	Well 8	0.0573	0.0036	0.0622	0.0186	0.0206	0.0265
11/02/00	Well 8	0.0541	0.0038	no data	no data	no data	no data
11/09/00	Well 8	0.0587	0.0036	0.0542	0.0174	0.0196	0.0259
11/16/00	Well 8	0.0590	0.0034	no data	no data	no data	no data
11/23/00	Well 8	0.0671	0.0039	0.0500	0.0183	0.0191	0.0264
11/30/00	Well 8	0.0646	0.0034	no data	no data	no data	no data
12/07/00	Well 8	0.0611	0.0032	0.0636	0.0190	0.0260	0.0335
12/14/00	Well 8	0.0663	0.0038	no data	no data	no data	no data
12/21/00	Well 8	0.0619	0.0033	0.0660	0.0200	0.0246	0.0304
12/28/00	Well 8	0.0611	0.0034	no data	no data	no data	no data
01/04/01	Well 8	0.0640	0.0036	0.0471	0.0145	0.0143	0.0188
01/11/01	Well 8	0.0592	0.0035	no data	no data	no data	no data
01/18/01	Well 8	0.0608	0.0035	0.0674	0.0180	0.0207	0.0258
01/25/01	Well 8	0.0469	0.0043	no data	no data	no data	no data
02/01/01	Well 8	0.0556	0.0029	0.0622	0.0179	0.0235	0.0286
02/08/01	Well 8	0.0629	0.0027	no data	no data	no data	no data
02/15/01	Well 8	0.0747	0.0030	0.0670	0.0194	0.0235	0.0270
03/01/01	Well 8	0.0641	0.0025	0.0679	0.0205	0.0298	0.0350
03/15/01	Well 8	0.0652	0.0025	0.0708	0.0217	0.0321	0.0367
03/29/01	Well 8	0.0743	0.0037	0.0756	0.0214	0.0251	0.0298
04/12/01	Well 8	0.0722	0.0036	0.0746	0.0214	0.0277	0.0322
04/26/01	Well 8	0.0751	0.0036	0.0798	0.0229	0.0303	0.0356
05/10/01	Well 8	0.0688	0.0028	0.0708	0.0217	0.0294	0.0341
05/24/01	Well 8	0.0651	0.0029	0.0783	0.0235	0.0310	0.0365
06/07/01	Well 8	0.0499	0.0076	0.0608	0.0276	0.0341	0.0415
06/21/01	Well 8	0.0827	0.0059	0.0765	0.0231	0.0256	0.0300
07/05/01	Well 8	0.0593	0.0027	0.0464	0.0111	0.0138	0.0157
07/19/01	Well 8	0.0586	0.0025	0.0447	0.0107	0.0124	0.0141
08/02/01	Well 8	0.0608	0.0031	0.0609	0.0164	0.0233	0.0272
08/16/01	Well 8	0.0591	0.0037	0.0467	0.0142	0.0146	0.0176
08/30/01	Well 8	0.0534	0.0031	0.0578	0.0151	0.0206	0.0240
09/13/01	Well 8	0.0576	0.0028	0.0636	0.0186	0.0242	0.0288
09/27/01	Well 8	0.0179	0.0021	0.0098	0.0030	0.0050	0.0036
10/11/01	Well 8	0.0565	0.0031	0.0532	0.0149	0.0180	0.0180
10/25/01	Well 8	0.0564	0.0032	0.0569	0.0168	0.0210	0.0225
11/08/01	Well 8	0.0577	0.0034	0.0437	0.0104	0.0106	0.0096
11/22/01	Well 8	0.0467	0.0029	0.0386	0.0087	0.0093	0.0075
12/08/01	Well 8	0.0223	0.0000	0.0446	0.0103	0.0118	0.0104
12/20/01	Well 8	0.0286	0.0018	0.0605	0.0159	0.0132	0.0175
01/03/02	Well 8	0.0393	0.0022	0.0508	0.0127	0.0161	0.0159
01/17/02	Well 8	0.0425	0.0022	0.0615	0.0146	0.0196	0.0186
01/31/02	Well 8	0.0657	0.0026	0.0597	0.0153	0.0201	0.0188
02/14/02	Well 8	0.0475	0.0022	0.0632	0.0135	0.0187	0.0172

Date	Location	Cl	SO_4	Na	K	Mg	Ca
02/28/02	Well 8	0.0642	0.0066	0.0529	0.0000	0.0088	0.0064
03/14/02	Well 8	0.0822	0.0066	0.0539	0.0016	0.0092	0.0077
03/28/02	Well 8	0.0799	0.0067	0.0526	0.0000	0.0091	0.0070
04/11/02	Well 8	0.0842	0.0067	0.0534	0.0000	0.0093	0.0132
04/25/02	Well 8	0.0831	0.0067	0.0597	0.0052	0.0108	0.0156
05/09/02	Well 8	0.0894	0.0065	0.0737	0.0000	0.0135	0.0174
05/23/02	Well 8	0.0534	0.0032	0.0583	0.0000	0.0103	0.0140
06/06/02	Well 8	0.0550	0.0034	0.0701	0.0066	0.0020	0.0043
06/20/02	Well 8	0.0543	0.0033	0.0000	0.0060	0.0017	0.0000
07/04/02	Well 8	0.0553	0.0031	0.0669	0.0000	0.0106	0.0129
07/19/02	Well 8	0.0561	0.0034	0.0615	0.0000	0.0127	0.0141
08/01/02	Well 8	0.0504	0.0030	0.0596	0.0055	0.0117	0.0148
08/15/02	Well 8	0.0143	0.0000	0.0640	0.0000	0.0112	0.0135
08/29/02	Well 8	0.0480	0.0030	0.0665	0.0000	0.0138	0.0172
09/12/02	Well 8	0.0505	0.0031	0.0572	0.0000	0.0115	0.0152
09/26/02	Well 8	0.0508	0.0030	0.0670	0.0056	0.0134	0.0163

Appendix 4. Summary of the gaps in the streamflow data set for the Arboleda and Taconazo streams between 12/98 and 11/02.

"Avg Gap Q", listed in the last column, is the predicted stream discharge determined through the use of a regression equation. Gaps labeled with an asterisk (*) indicate that the straight-line method was used rather than a regression equation due to due missing antecedent data.

Gap Start			Gap End			Duration	Avg Gap
Date	Day	Time	Date	Day	Time	(days)	Q (m^3/min)
Arboleda 12/98-11/99							
12/04/98	338	2320	12/05/98	339	1230	0.55	20.02
12/17/98	351	2300	01/25/99	25	1100	38.49	19.96
06/01/99	152	1320	06/15/99	166	930	13.84	19.92
11/03/99	307	730	11/03/99	307	1610	0.36	19.14
*11/04/99	308	1110	11/05/99	309	340	0.69	14.52
*11/06/02	310	250	11/06/99	310	2040	0.74	20.48
*11/29/99	334	1130	12/01/99	335	230	0.63	15.25
Arboleda 12/99-11/00							
12/03/99	337	120	12/05/99	339	1230	2.47	20.21
12/06/99	340	720	02/16/00	47	1500	72.31	13.21
05/27/00	147	1930	05/28/00	148	400	0.35	10.42
05/28/00	148	1915	05/29/00	149	545	0.44	12.93
07/15/00	196	415	07/16/00	197	815	1.17	15.23
07/26/00	207	630	07/26/00	207	1630	0.42	17.33
07/26/00	207	2200	07/27/00	208	615	0.34	23.72
07/29/00	210	1800	07/30/00	211	1345	0.82	16.83
08/15/00	227	1800	08/16/00	228	745	0.57	19.29
10/20/00	293	1000	10/21/00	294	0	0.58	15.35
11/20/00	324	2045	11/21/00	325	1230	0.66	11.41
Arboleda 12/00-11/01							
12/06/00	340	1745	12/07/00	341	515	0.48	11.72
01/02/01	2	1400	01/02/01	2	2230	0.35	21.11
01/26/01	26	115	01/27/01	27	1145	1.44	9.76
06/26/01	177	1330	06/26/01	177	2200	0.35	28.07
06/28/01	179	330	07/05/01	186	815	7.20	39.07
07/18/01	199	1300	07/19/01	200	15	0.47	20.79
08/10/01	222	1830	08/17/01	229	830	6.58	48.84
11/14/01	318	2330	11/15/01	319	815	0.36	15.64
11/16/01	320	2200	11/18/01	322	1530	1.73	38.38
Arboleda 12/01-11/02							

Gap Start Date	Gap Start Day	Gap Start Time	Gap End Date	Gap End Day	Gap End Time	Duration (days)	Avg Gap Q (m^3/min)
12/05/01	339	1945	12/07/01	341	1415	1.77	56.55
12/12/01	346	815	12/14/01	348	2000	2.49	47.15
01/07/02	7	1445	01/10/02	10	1245	2.92	10.54
02/08/02	39	900	02/08/02	39	900	0.01	10.34
02/11/02	42	1515	02/15/02	46	900	3.74	3.79
05/05/02	125	715	05/06/02	126	530	0.93	27.36
05/06/02	126	645	05/07/02	127	600	0.97	46.15
05/09/02	129	830	05/09/02	129	1615	0.32	19.35
05/10/02	130	1900	05/11/02	131	1115	0.68	44.52
*05/15/02	135	45	05/15/02	135	2300	0.93	18.85
07/10/02	191	45	07/10/02	191	1545	0.63	62.52
07/19/02	200	1715	07/20/02	201	1300	0.82	36.03
08/07/02	219	645	08/07/02	219	1500	0.34	28.29
08/15/02	227	845	08/15/02	227	1630	0.32	15.27
*08/21/02	233	2145	08/22/02	234	1400	0.68	8.99
08/26/02	238	1900	08/27/02	239	1945	1.03	38.03
11/17/02	321	1345	11/19/02	323	1615	2.10	23.24
11/29/02	333	630	11/30/02	334	2400	1.73	28.39
Taconazo 12/98-11/99							
12/18/98	352	410	01/08/99	8	1510	21.44	4.06
01/12/99	12	1420	01/18/99	18	1340	5.97	7.36
01/19/99	19	830	01/29/99	29	1310	10.19	3.74
02/02/99	33	110	02/09/99	40	1050	7.40	2.80
06/08/99	159	820	06/22/99	173	930	14.05	1.71
11/03/99	307	940	11/03/99	307	1140	0.08	4.46
11/04/99	308	1330	11/04/99	308	2040	0.30	2.25
11/06/99	310	340	11/06/99	310	1410	0.44	3.65
11/30/99	334	1600	11/30/99	334	2200	0.25	1.15
Taconazo 12/99-11/00							
12/03/99	337	440	12/03/99	337	1920	0.61	10.66
12/03/99	337	2050	02/16/00	47	930	74.51	1.82
05/26/00	147	2030	05/26/00	147	2230	0.08	0.71
05/27/00	148	2030	05/28/00	149	0	0.15	1.52
07/14/00	196	715	07/14/00	196	1530	0.34	13.28
07/23/00	205	2300	12/01/00	336	800	130.38	1.22
Taconazo 12/00-11/01							
01/02/01	2	1430	01/02/01	2	1900	0.19	4.10
01/26/01	26	330	01/26/01	26	630	0.13	2.11
02/09/01	40	745	02/09/01	40	745	0.01	1.27
04/06/01	96	730	04/06/01	96	800	0.02	0.22

Gap Start			Gap End			Duration	Avg Gap
Date	Day	Time	Date	Day	Time	(days)	Q (m^3/min)
06/01/01	152	830	06/01/01	152	845	0.01	0.50
06/28/01	179	515	07/05/01	186	915	7.17	6.01
07/18/01	199	1400	07/18/01	199	1945	0.24	4.59
11/17/01	321	545	11/17/01	321	1715	0.48	35.33
11/18/01	322	545	11/18/01	322	1015	0.19	8.93
Taconazo 12/01-11/02							
12/05/01	339	2130	12/07/01	341	1130	1.58	8.14
12/12/01	346	915	12/14/01	348	1915	2.42	8.32
01/07/02	7	1515	01/08/02	8	2000	1.20	3.81
*01/09/02	9	45	01/09/02	9	1345	0.54	3.25
05/05/02	125	815	05/05/02	125	2330	0.64	3.58
05/06/02	126	730	05/07/02	127	500	0.90	10.26
05/15/02	135	530	05/15/02	135	1645	0.47	5.63
07/10/02	191	100	07/10/02	191	1200	0.46	3.51
07/19/02	200	1945	07/20/02	201	245	0.29	9.22
08/07/02	219	745	08/07/02	219	1145	0.17	4.70
08/21/02	233	2245	08/22/02	234	1045	0.50	8.99
08/26/02	238	1945	08/27/02	239	645	0.46	8.64
11/17/02	321	2300	11/18/02	322	2100	0.92	8.75
11/29/02	333	1030	11/30/02	334	2400	1.56	3.51

Appendix 5. Data used to develop a regression to fill short gaps in the Taconazo stream discharge data set.

"Avg Q" refers to the average stream discharge that occurred between the start and end dates/times. "Block" refers to the rainfall that occurred between the start and end dates/times. "Stream Q 0-6 hours" refers to the volumetric stream discharge that was measured 6 hours before the start date/time. "Stream Q" is the predicted stream discharge based on the regression listed below the table.

Start		**End**		**Avg Q**	**Rainfall (mm)**	**Stream Q**	**Stream**
Date	**Time**	**Date**	**Time**	**(m^3/min)**	**Block**	**0-6 hours (m^3)**	**Q (m^3)**
07/04/98	700	07/04/98	1850	3.13	44.7	483.16	3725
08/30/98	700	09/01/98	650	0.70	14.2	226.08	1272
02/10/99	700	02/12/99	1850	0.40	5.5	144.76	518
04/01/99	700	04/01/99	1850	0.17	0.0	73.40	-93
06/23/99	700	06/24/99	650	0.94	0.0	356.40	1816
08/05/99	700	08/07/99	650	2.03	19.8	596.12	3900
09/17/99	700	09/19/99	650	0.83	41.2	169.88	1529
02/17/00	700	02/18/00	645	1.46	6.0	573.80	3424
03/24/00	700	03/26/00	1845	0.37	0.0	149.94	423
04/29/00	700	04/29/00	1845	0.34	0.1	165.35	530
05/28/00	700	05/28/00	1845	0.84	15.7	372.06	2292
06/19/00	700	06/19/00	1845	1.73	12.9	492.80	3040
01/03/01	700	01/05/01	645	2.66	9.9	1076.26	6905
02/10/01	700	02/10/01	1845	1.20	0.5	398.92	2115
03/11/01	700	03/11/01	1845	0.32	0.0	122.40	238
04/07/01	700	04/09/01	645	0.52	47.8	76.61	1055
11/07/98	700	11/09/98	1850	2.39	12.2	1151.89	7470
10/25/98	700	10/26/98	650	1.49	0.0	580.54	3328
11/22/98	700	11/24/98	1845	0.97	7.7	385.20	2192
11/30/98	700	12/01/98	645	1.34	29.4	412.81	2890
05/23/99	700	05/25/99	1850	0.64	10.3	261.83	1421
12/02/00	700	12/03/00	645	1.93	0.0	456.12	2489

Stream Q (m^3) = 23.6 (block rain) - 6.7 (Q 0-6 hours) - 588.1

$r^2 = 0.757$

Appendix 6. Data used to develop a regression to fill long gaps in the Taconazo stream discharge data set.

"Avg Q" refers to the average stream discharge that occurred between the start and end dates/times. "Block" refers to the rainfall that occurred between the start and end dates/times. "1-15 days", "16-35 days", and "36-60 days" refer to the rainfall that was measured during the stated number of days prior to the start date/time. "Stream Q" is the predicted stream discharge based on the regression listed below the table.

Start		**End**		**Avg Q**	**Rainfall (mm)**				**Stream**
Date	**Time**	**Date**	**Time**	**(m^3/min)**	**Block**	**1-15 days**	**16-35 days**	**36-60 days**	**Q (m^3)**
07/04/98	700	08/29/98	650	1.33	594.2	197.9	302.6	219.6	89820
08/30/98	700	10/25/98	650	0.95	607.8	184.7	39.4	155.9	73715
02/10/99	700	03/31/99	650	0.35	264.6	29.4	148.1	329.4	27990
04/01/99	700	05/20/99	650	0.61	622.9	77.8	60.1	34.4	62311
06/23/99	700	08/04/99	650	1.52	727.7	86.2	251.8	195.8	91400
08/05/99	700	09/16/99	650	1.03	254.9	274.1	277.8	183.7	53734
09/17/99	700	10/29/99	650	1.41	753.3	80.1	49.3	139.7	81030
02/17/00	700	03/23/00	645	1.08	251.5	306.7	137.3	403.2	55624
03/24/00	700	04/28/00	645	0.47	230.9	18.1	171.5	233.3	21091
04/29/00	700	05/20/00	645	0.31	82.8	55.4	175.5	11.6	180
05/28/00	700	06/18/00	645	1.03	307.8	119.0	72.5	48.8	29289
06/19/00	700	07/10/00	645	1.76	418.4	201.9	205.4	50.4	58301
01/03/01	700	01/24/01	645	1.54	155.7	267.4	132.1	221.8	34196
02/10/01	700	03/10/01	645	0.63	233.6	69.2	140.5	217.1	24286
03/11/01	700	03/25/01	645	0.29	26.4	20.2	214.5	106.8	-5069
04/07/01	700	04/21/01	645	0.79	238.4	73.1	16.5	18.9	12304
11/07/98	700	11/21/98	645	1.62	97.6	289.3	332.3	63.4	35427
10/25/98	700	11/01/98	650	1.51	70.0	295.4	103.3	103.9	21344
11/22/98	700	11/29/98	645	1.12	94.4	97.6	289.3	332.3	21960
11/30/98	700	12/07/98	645	2.11	176.1	160.7	250.8	170.7	31023
11/07/99	700	11/28/99	650	1.28	105.7	243.6	324.1	195.3	35503
05/23/99	700	06/06/99	650	0.93	231.6	190.7	257.2	186.9	41591
12/02/00	700	12/23/00	645	1.26	203.3	211.8	140.1	253.6	35876

Stream Q (m^3) = 121.4 (block rain) + 99.3 (rain 1-15 days) + 55.0 (rain 16-35 days) + 30.9 (rain 36-60 days) - 25379

$r^2 = 0.885$

Appendix 7. Data used to develop a regression to fill short gaps in the Arboleda stream discharge data set.

"Avg Q" refers to the average stream discharge that occurred between the start and end dates/times. "Block" refers to the rainfall that occurred between the start and end dates/times. "1-5 days", "6-10 days", and "11-20 days" refer to the rainfall that was measured during the states number of days prior to the start date/time. "Stream Q" is the predicted stream discharge based on the regression listed below the table.

Start		**End**		**Avg Q**	**Rainfall (mm)**				**Stream**
Date	**Time**	**Date**	**Time**	**(m^3/min)**	**Block**	**1-5 days**	**6-10 days**	**11-20 days**	**Q (m^3)**
07/05/98	700	07/07/98	1850	12.10	25.8	96.4	78.3	112.5	27701
08/04/98	700	08/06/98	650	10.43	9.2	15.4	76.4	74.2	20212
01/26/99	700	01/27/99	650	10.55	2.0	65.2	9.1	88.3	11247
03/17/99	700	03/18/99	650	9.59	24.6	11.2	47.7	22.4	22340
06/16/99	700	06/18/99	1850	10.34	0.0	24.0	78.6	165.4	20799
07/30/99	700	07/30/99	1850	12.31	14.7	125.6	65.2	248.8	28086
09/10/99	700	09/10/99	1850	9.31	0.1	40.2	36.5	23.2	9731
02/17/00	700	02/19/00	1845	11.24	32.3	8.0	26.1	274.4	37467
03/24/00	700	03/24/00	1845	9.09	0.0	3.7	12.0	61.7	10797
04/29/00	700	05/01/00	645	11.16	27.0	30.8	14.5	129.6	25991
05/29/00	700	05/29/00	1845	9.91	3.8	102.3	13.0	38.9	8783
06/20/00	700	06/22/00	645	13.19	53.0	122.7	35.3	126.4	36690
08/16/00	700	08/17/00	645	12.03	17.6	110.4	71.3	116.8	23330
09/14/00	700	09/14/00	1845	10.00	0.0	40.8	3.5	89.3	10616
10/20/00	700	10/22/00	1845	12.32	51.0	67.1	12.4	122.8	35318
10/28/00	700	10/28/00	1845	10.06	0.9	23.5	88.5	78.3	17403
11/05/00	700	11/05/00	1845	13.23	0.0	124.0	110.8	125.9	18548
12/06/00	700	12/08/00	645	10.70	2.3	59.0	36.4	209.3	19987
01/03/01	700	01/04/01	645	13.96	8.1	168.4	67.8	66.6	14619
02/17/01	700	02/17/01	1845	9.99	0.0	207.7	14.0	27.3	3756
11/07/98	700	11/07/98	1845	14.12	0.6	215.0	41.2	134.0	11515
12/06/98	700	12/07/98	650	12.81	10.6	131.0	112.6	72.3	20458
11/07/99	700	11/09/99	1845	13.39	70.0	79.3	53.8	296.7	55844
05/17/99	700	05/17/99	1845	9.25	22.4	9.4	9.7	86.7	21866
07/30/00	700	08/01/00	645	12.49	22.9	111.1	90.9	165.7	29764

Stream Q (m^3) = 450.1 (block rain) - 26.4 (rain 1-5 days) + 76.5 (rain 6-10 days) + 52.5 (rain 11-20 days) + 6737.9

$r^2 = 0.617$

Appendix 8. Data used to develop a regression to fill long gaps in the Arboleda stream discharge data set.

"Avg Q" refers to the average stream discharge that occurred between the start and end dates/times. "Block" refers to the rainfall that occurred between the start and end dates/times. "1-5 days", "6-10 days", and "11-20 days" refer to the rainfall that was measured during the stated number of days prior to the start date/time. "Stream Q" is the predicted stream discharge based on the regression listed below the table.

Start		End		Avg Q	Rainfall (mm)				Stream
Date	**Time**	**Date**	**Time**	**(m^3/min)**	**Block**	**1-15 days**	**16-35 days**	**36-60 days**	**Q (m^3)**
07/05/98	700	08/30/98	650	11.08	557.8	222.4	293.6	163.5	731541
08/04/98	700	10/19/98	650	10.28	563.0	122.0	203.9	219.5	719282
01/26/99	700	03/16/99	650	9.29	213.8	150.2	329.0	651.3	551539
03/17/99	700	05/12/99	650	9.52	540.7	60.1	34.4	114.3	598528
06/16/99	700	07/29/99	650	11.69	676.4	230.5	227.2	34.1	787002
07/30/99	700	09/09/99	650	10.93	336.4	292.9	247.9	161.1	491084
09/10/99	700	10/22/99	650	10.45	618.5	79.6	74.9	246.0	738212
02/17/00	700	03/23/00	645	10.57	251.5	314.4	367.9	198.9	459455
03/24/00	700	04/28/00	645	9.48	230.9	18.1	171.5	233.3	365744
04/29/00	700	05/20/00	645	9.44	82.8	55.4	175.5	11.6	141841
05/29/00	700	06/19/00	645	11.03	304.9	134.7	62.6	55.4	350026
06/20/00	700	07/11/00	645	13.75	407.0	205.6	213.8	51.2	509887
08/16/00	700	09/13/00	645	12.48	349.1	253.9	230.7	272.3	533717
09/14/00	700	10/12/00	645	10.34	249.6	92.7	281.3	235.1	427732
10/20/00	700	10/27/00	645	11.16	74.5	158.6	106.0	97.9	143957
10/28/00	700	11/04/00	645	13.79	219.1	146.0	130.8	118.7	307566
11/05/00	700	11/12/00	645	11.79	16.1	292.2	147.7	118.3	112522
12/06/00	700	12/20/00	645	11.00	117.0	211.8	140.1	253.6	255078
01/03/01	700	01/17/01	645	11.72	124.2	267.4	132.1	221.8	251929
02/17/01	700	03/03/01	645	9.45	1.9	240.4	173.9	51.0	81444
11/07/98	700	11/28/98	650	11.30	184.3	289.3	332.3	63.4	330780
12/06/98	700	12/13/98	650	12.81	118.9	255.8	175.7	211.8	257613
11/07/99	700	11/28/99	650	10.89	105.7	243.6	324.1	195.3	289343
05/17/99	700	05/31/99	650	10.03	227.1	34.2	342.0	91.3	373840
07/30/00	700	08/13/00	645	12.60	235.1	226.8	312.5	349.6	469666

Stream Q (m^3) = 1027.9 (block rain) + 53.9 (rain 1-15 days) + 347.3 (rain 16-35 days) + 338.6 (rain 36-60 days) - 11136.8

$r^2 = 0.769$

Appendix 9. Uncertainty in Water Budget Terms

Uncertainty in Stream Discharge

The uncertainty in annual stream discharge, W_{Qs}, for both watersheds is expected to be approximately 5 percent (Williams and Melack 1997; Lesack and Melack 1995; Lesack 1993; Winter 1981):

$$W_{Qs} = 0.05\ (Qs) \qquad \text{(A9-1)}$$

where Q_S is the annual stream discharge and W_{Qs} is the uncertainty in the annual stream discharge. One value of annual W_S was calculated for each watershed, for each budget year. To determine the uncertainty in a single measurement of stream discharge, which is typically recorded every 15 minutes, the value for W_{Qs} from equation A9-1 was used working backwards to find Ws:

$$W_{Qs} = \sqrt{35040 \quad (Ws)^2} \qquad \text{(A9-2)}$$

where W_S is the uncertainty in a single stream discharge measurement and there are 35040 stream discharge measurements in a year (35040 15-minute intervals in a non-leap year). The uncertainty in a single stream discharge measurement is needed because the f_{GS}, Q_{GI}, and Q_{GS} for the Arboleda water budget were calculated on 15-minute intervals.

The stream discharge for the Arboleda is composed of local water and bedrock groundwater. The uncertainty of each end-member component was determined based on 15-minute intervals using the uncertainty in stream discharge, Ws, and the uncertainty in the fraction of stream discharge that is bedrock groundwater, f_{GS}. The uncertainty in f_{GS}, W_f, is a function of the uncertainty in the end-member chloride concentrations and the uncertainty in the regression used to predict the chloride concentration in the Arboleda (Figure 17) (Genereux 1998):

$$W_f = \sqrt{\left[\frac{C_{BGW} - C_S}{(C_{BGW} - C_{LW})^2} \cdot W_{LW}\right]^2 + \left[\frac{C_S - C_{LW}}{(C_{BGW} - C_{LW})^2} \cdot W_{BGW}\right]^2 + \left[\frac{-1}{(C_S - C_{LW})} \cdot W_S\right]^2} \qquad \text{(A9-3)}$$

where C represents the chloride concentrations, W represents uncertainty, and the subscripts LW, BGW, and S refer to local water, bedrock groundwater, and the Arbo stream site, respectively. The values used for W_{LW} and W_{BGW} were the standard deviations of the average Cl concentrations in local water and bedrock groundwater (Table 6). The value used for Ws was the average of the absolute value of the residuals from the regression equation that predicts chloride concentration with variation in stream discharge. Using W_f and Ws, the uncertainty in bedrock groundwater component of the stream discharge, W_{GS}, was calculated:

$$W_{GS} = \sqrt{(Q_S W_f)^2 + (f_{GS} W_{Qs})^2} \qquad \text{(A9-4)}$$

The uncertainty in Q_{GI} was the same as the uncertainty for Q_{GS} that was calculated using Equation A9-4. $Q_{LS} = Q_S - Q_{GS}$ and the uncertainty for Q_{LS} was calculated as the quadratic sum of the uncertainty in Q_S and Q_{GS}:

$$W_{LS} = \sqrt{(W_{Qs})^2 + (W_{GS})^2} \qquad \text{(A9-5)}$$

Q_{LI} was calculated from Equation 4-3, and the uncertainty in Q_{LI} was calculated as the quadratic sum of the uncertainties in all the terms in the water budget:

$$W_{LI} = \sqrt{(P)^2 + (W_{GI})^2 + (W_{ET})^2 + (W_{LS})^2 + (W_{GS})^2} \qquad \text{(A9-6)}$$

Uncertainty in Evapotranspiration (based on Devore 2000, p. 37, 499, and 521)
The evapotranspiration value for each budget year was predicted using a linear regression equation with a form of:

$$\hat{y} = \beta_o + \beta\,(x) \qquad \text{(A9-7)}$$

where $\hat{y}$ is the predicted evapotranspiration value based on the regression equation with constants for the y-intercept, β_o, and the slope, β. The regression equation that predicts evapotranspiration was based on annual estimates of evapotranspiration (Loescher 2002) and total incident solar radiation measurements (OTS). The regression equation was developed using Sigma Plot 8.0:

$$\hat{y} = -148.4279 + 1.0826\,(x) \quad (r^2 = .974) \qquad \text{(A9-8)}$$

The uncertainty in the expected evapotranspiration value, $\hat{y}$, when x is equal to x* is expressed as:

$$\hat{y} \pm t_{\alpha/2,\,n-2} \cdot s_{\hat{y}} \qquad \text{(A9-9)}$$

The value for t is obtained from a t-distribution table (Kendall and Stewart 1966) and is a function of the confidence interval (represented by α) and the number of samples (n). The standard deviation of the statistic $\hat{y}$ is expressed as:

$$s_{\hat{y}} = s\,[\,1/n + (x^* - \bar{x}\,)^2/S_{xx}\,]^{0.5} \qquad \text{(A9-10)}$$

where s is the sample standard deviation and n is the sample size. x* is the value of total solar radiation (TSR) obtained from OTS that is used to the predict evapotranspiration for each budget year. S_{xx} is defined as:

$$S_{xx} = \Sigma x_i^2 - (\Sigma x_i)^2/n \quad \text{(A9-11)}$$

where x_i are evapotranspiration values determined by Loescher (2002) that were used to create the regression. The sample standard deviation, s, was calculated from the sample variance, s^2, which is expressed as:

$$s^2 = S_{xx}/(n-1) \quad \text{(A9-12)}$$

Data used to develop the regression that predicts evapotranspiration:

Year	ET (mm) Loescher (2002)	TSR (mm) (OTS)
1998	1894	1892
1999	2285	2294
2000	2157	2230

Regression Equation:
$\hat{y} = -148.4279 + 1.0826\,(x) \quad (r^2 = .974)$

Additional Variables:
n= 3
x_i = 1894; 2285; 2157
$\overline{x}_i$ = 2114
$\Sigma x_i^2 = 1894^2 + 2285^2 + 2157^2 = 13{,}452{,}228$
$(\Sigma x_i)^2 = (1894 + 2285 + 2157)^2 = 40{,}119{,}556$
x* = 2303; 2114; 1948; 1968

confidence interval of 70 percent ($\alpha = 0.30$)
3 samples – 2 = 1 (value for *v*, 1 degree of freedom)
t = 1.963 (Kendall and Stewart 1966) based on $v = 1$ and $\alpha = 0.30$

Calculation Summary:

Year	12/98-11/99	12/99-11/00	12/00-11/01	12/01-11/02
x^*	2,303	2,114	1,948	1,968
$\hat{y}$	2,345	2,141	1,961	1,983
S_{xx}	79,042	79,042	79,042	79,042
s^2	39,521	39,521	39,521	39,521
s	199	199	199	199
$s_{\hat{y}}$	176	115	165	155
$t_{\alpha/2,\, n-2} \cdot s_{\hat{y}}$	345	225	323	303
ET	**2345 ± 345**	**2141 ± 225**	**1961 ± 323**	**1983 ± 303**

Appendix 10. Approximate monthly totals for the water budget components for the Taconazo and Arboleda watersheds.

In order to estimate the monthly interbasin transfer of local water into each watershed, the annual evapotranspiration was divided by 12 to provide an approximate evapotranspiration value for each month.

	ARBOLEDA WATERSHED					**TACONAZO WATERSHED**		
	Inputs (mm)			**Outputs (mm)**		**Inputs (mm)**		**Outputs (mm)**
	Precip	**Q_{GI}**	**Q_{LI}**	**Q_{GS}**	**Q_{LS}**	**Precip**	**Q_{LI}**	**Q_S**
Dec-98	1,061	354	266	354	1,131	1,061	-323	542
Jan-99	296	348	1,145	348	1,246	296	558	658
Feb-99	149	344	456	344	410	149	213	166
Mar-99	137	382	470	382	411	137	107	49
Apr-99	419	367	261	367	485	419	-118	106
May-99	273	380	402	380	480	273	29	106
Jun-99	395	331	770	331	969	395	55	254
Jul-99	568	372	351	372	723	568	-104	268
Aug-99	208	377	597	377	609	208	222	234
Sep-99	239	369	411	369	455	239	54	98
Oct-99	618	373	267	373	690	618	-124	299
Nov-99	857	361	3	361	665	857	-410	252
Dec-99	583	367	459	367	863	583	-70	334
Jan-00	553	370	434	370	809	553	-67	308
Feb-00	474	348	403	348	698	474	-18	277
Mar-00	86	381	574	381	481	86	201	109
Apr-00	247	368	402	368	470	247	15	83
May-00	202	381	446	381	470	202	40	64
Jun-00	513	360	349	360	684	513	-87	247
Jul-00	544	366	501	366	867	544	-95	270
Aug-00	527	369	462	369	811	527	-142	207
Sep-00	211	366	514	366	547	211	167	200
Oct-00	374	376	415	376	610	374	12	207
Nov-00	375	361	494	361	690	375	3	200
Dec-00	361	375	454	375	651	361	31	228
Jan-01	326	374	505	374	667	326	126	288
Feb-01	98	343	527	343	461	242	47	126
Mar-01	89	382	506	382	432	89	135	61
Apr-01	293	369	320	369	450	293	-41	88
May-01	148	381	465	381	450	148	77	62
Jun-01	760	348	305	348	901	760	-323	274
Jul-01	407	350	939	350	1,183	407	239	482
Aug-01	362	378	374	378	572	362	39	237
Sep-01	262	366	434	366	533	262	68	166
Oct-01	403	375	407	375	647	403	28	267

	ARBOLEDA WATERSHED					TACONAZO WATERSHED		
	Inputs (mm)			**Outputs (mm)**		**Inputs (mm)**		**Outputs (mm)**
	Precip	**Q_{GI}**	**Q_{LI}**	**Q_{GS}**	**Q_{LS}**	**Precip**	**Q_{LI}**	**Q_S**
Nov-01	773	341	500	341	1,110	773	42	652
Dec-01	1,099	334	551	334	1,485	1,099	-176	758
Jan-02	348	376	449	376	631	348	114	297
Feb-02	135	341	439	341	408	135	178	148
Mar-02	125	381	493	381	453	125	108	68
Apr-02	171	370	401	370	407	171	30	36
May-02	831	354	431	354	1,096	831	-125	540
Jun-02	524	356	431	356	790	524	31	390
Jul-02	653	354	629	354	1,117	653	95	583
Aug-02	617	357	602	357	1,053	617	186	637
Sep-02	422	360	428	360	684	422	108	365
Oct-02	282	377	474	377	591	282	82	198
Nov-02	473	355	472	355	780	473	-15	293

Appendix 11. Uncertainty in Chemical Budget Terms

Uncertainty in Atmospheric Solute Inputs

The uncertainty in solute input by precipitation was calculated for each ion for each weekly bulk rain sample. The uncertainty of the weekly input was based on the uncertainty in the tipping bucket rainfall data (in mm) and the uncertainty in the chemical analysis for each solute. The uncertainty in the chemical analysis for the major anions and cations using ion chromatography (IC) was determined based standards that were run with the samples. The uncertainty in the concentration of an ion determined using IC was calculated as the average of the absolute value of the percent difference, for standards, between the true concentration and the concentration determined by the IC. The uncertainties for each ion were:

Ion	**Uncertainty**
Cl	2.65%
SO_4	2.71%
Na	2.28%
K	3.46%
Mg	1.95%
Ca	3.36%

The uncertainty in rainfall is estimated to be approximately 7 percent (see section 4.3) (Winter 1981). The uncertainty in each weekly solute input (in mol/ha) was calculated using the depth of rainfall during that week (P in mm), uncertainty in rainfall (W_P), ion concentration (C), ion concentration uncertainty (W_C), and a unit conversion factor of 10:

$$W = \sqrt{(P \bullet W_C \bullet 10)^2 + (W_P \cdot C \bullet 10)^2} \qquad \text{AP11-1}$$

The annual uncertainty was calculated as the root-mean-square sum of the weekly uncertainties.

Uncertainty in Solute Input by IGT of Local Water and Bedrock Groundwater

The annual uncertainty in solute input by interbasin groundwater transfer of local water is based on the flux of groundwater input to the watershed (Q_{LI}), the local water solute concentration (C_L), the uncertainties in the groundwater flux (W_{QLI}) and solute concentration (W_{CL}), and a unit conversion factor of 10. The uncertainty in C_L was the standard deviation of the solute concentration in the local water end-member (Table 6) and the values used for the uncertainty in Q_{LI} were from the water budgets (Table 5). The annual uncertainty for each ion was calculated as:

$$W = \sqrt{(Q_{LI} \bullet W_{CL} \bullet 10)^2 + (C_L \bullet W_{QLI} \bullet 10)^2} \qquad \text{AP11-2}$$

The annual uncertainty in solute input by interbasin groundwater transfer of bedrock groundwater was calculated in a similar fashion to the interbasin transfer of local water. Equation AP11-2 was modified by substituting the bedrock groundwater end-member concentrations (C_G) and water fluxes (Q_{GI}). The uncertainty in C_G was the standard deviation of the solute concentration in the bedrock groundwater end-member (Table 6) and the values used for the uncertainty in Q_{GI} were from the water budgets (Table 5). The annual uncertainty for each ion was calculated as:

$$W = \sqrt{(Q_{GI} \bullet W_{CG} \bullet 10)^2 + (C_G \bullet W_{QGI} \bullet 10)^2} \qquad \text{AP11-3}$$

Uncertainty in Solute Export from the Arboleda Watershed

The uncertainty in dissolved export for the Arboleda watershed was calculated separately for the local water and bedrock groundwater fractions of stream flow. The bedrock groundwater portion of the stream flow was calculated in a similar manner to the interbasin transfer of bedrock groundwater. Because all the bedrock groundwater input to the watershed was discharged to the stream, the uncertainty in the dissolved solute export of bedrock groundwater was also calculated using Equation AP11-3.

The dissolved solute export for the local water portion of the stream flow was also calculated in a similar manner by substituting the values for the water flux (Q_{LS}) and the end-member concentrations for local water (C_L). The uncertainty in the dissolved solute export of local water was calculated as:

$$W = \sqrt{(Q_{LS} \bullet W_{CL} \bullet 10)^2 + (C_L \bullet W_{QLS} \bullet 10)^2} \qquad \text{AP11-4}$$

Uncertainty in Dissolved Solute Export from the Taconazo Watershed

The uncertainty in dissolved export from the Taconazo watershed was calculated for both the regression method (for Cl and Mg) and the weekly method (for Na, K, SO_4, and Ca). For the weekly method, the uncertainty in the weekly export of each of the four ions was calculated separately. The uncertainty of the weekly export was based on the uncertainty in the weekly stream discharge and the uncertainty in the chemical analysis of each solute. The uncertainty in the chemical analysis for each solute was estimated as explained in the section above on "Uncertainty in Atmospheric Solute Inputs". The uncertainty in weekly stream discharge is estimated to be 5 percent (see Appendix 9) (Williams and Melack 1997; Lesack and Melack 1995; Lesack 1993; Winter 1981). The uncertainty in the watershed area (W_A) was estimated to be 3 percent. The uncertainty (in moles) in each weekly solute export was calculated as:

$$W = \sqrt{(Q_{LS} \bullet W_C / A)^2 + (W_{QLS} \bullet C / A)^2 + (Q_{LS} \bullet C \bullet W_A / A^2)^2} \qquad \text{AP11-5}$$

The annual uncertainty was calculated as the root-mean-square sum of the weekly uncertainties and then divided by the area of the watershed to obtain units of mol/ha.

The uncertainty in the dissolved solute export as calculated by the regression method was determined in a similar fashion to the weekly method with the exception that the regression method was calculated on 15-minute intervals rather than weekly intervals. The uncertainty was determined based on the instantaneous stream discharge (Q_S), the uncertainty in each 15-minute discharge measurement (W_{QS}), the regression-predicted solute concentration (C_P), and the uncertainty in the predicted concentration (W_{CP}). The uncertainty in the predicted concentration, which was calculated as the average of the absolute value of the residuals, was 0.0079 mM for Cl (Figure AP11-1) and 0.0012 mM for Mg (Figure AP11-2). The uncertainty in each 15-minute stream discharge measurement (where there are 35,040 measurements in 1 year) was estimated based on the uncertainty of 5 percent in the total annual Q_S:

$$(\text{Annual } Q_S) \bullet (0.05) = \sqrt{(35{,}040)(\text{uncertainty in 15 - minute } Q_S)^2} \qquad \text{AP11-6}$$

The uncertainty in each 15-minute stream discharge measurement from 12/00-11/01 was 0.78 m^3 based on an annual stream discharge of 2,931 mm and 1.15 m^3 for 12/01-11/02 based on an annual stream discharge of 4,312 mm. The uncertainty in the watershed area (W_A) was estimated to be 3 percent. The uncertainty in each 15-minute solute export was calculated as:

$$W = \sqrt{(Q_S \cdot W_{CP} / A)^2 + (W_{QS} \cdot C_P / A)^2 + (Q_S \cdot C_P \cdot W_A / A^2)^2} \qquad \text{AP11-7}$$

The annual uncertainty was calculated as the root-mean-square sum of the 15-minute uncertainties and then divided by the area of the watershed to obtain units of mol/ha.

Figure AP11-1. Plot of residuals for predicted chloride concentration in mM (i.e., measured concentration minus predicted concentration) versus Taconazo stream discharge (in m^3/min).

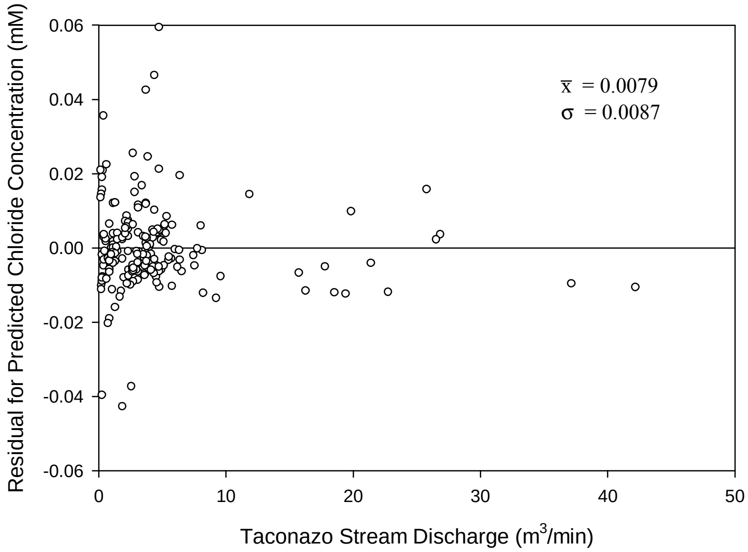
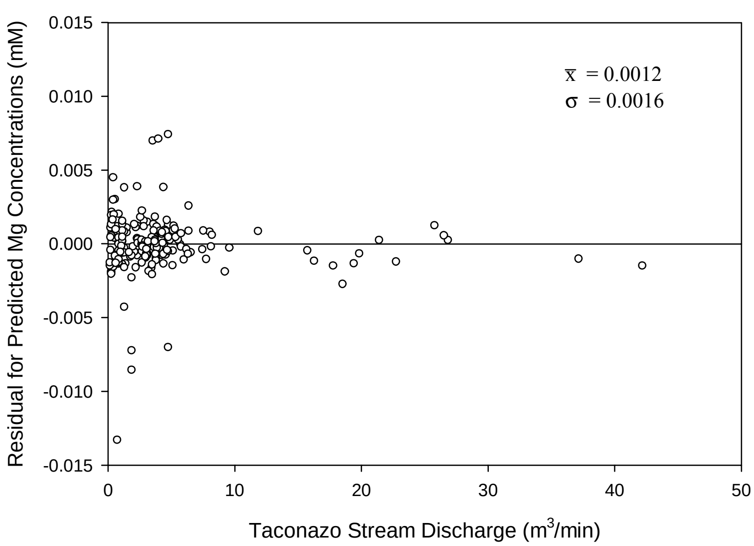


Figure AP11-2. Plot of residuals for predicted magnesium concentration (in mM) versus Taconazo stream discharge (in m^3/min).



Appendix 12. Effects of insect contamination on bulk rainfall chemistry.

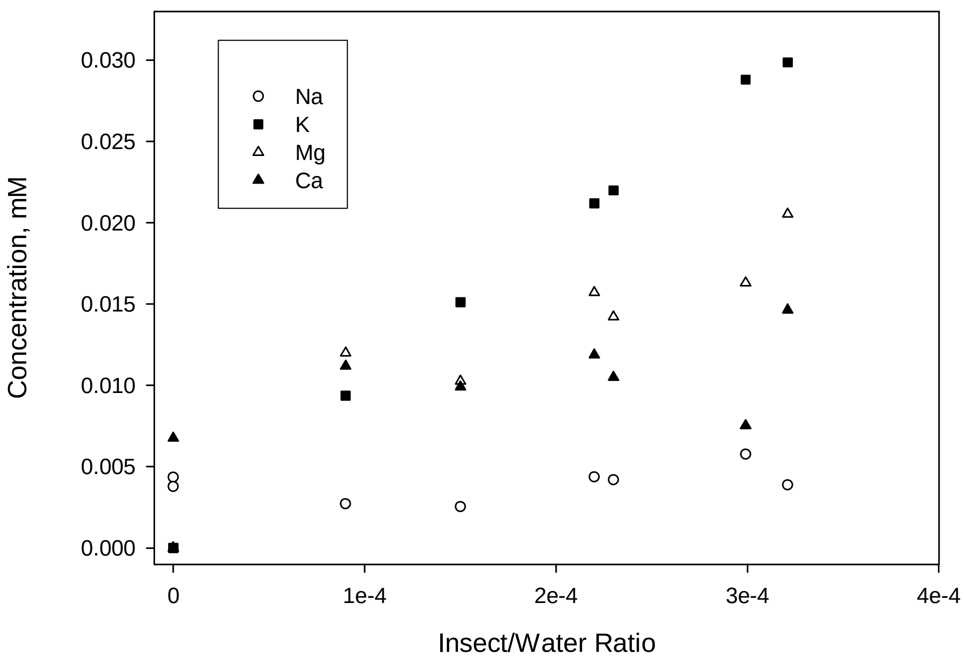
Twelve live Cercopoidae were collected in July 2000 using a net in tall grass beneath the tower with the bulk rainfall collector. The live insects were placed in a 1-gallon clear plastic bottle with air-holes in the cap for transport back to the lab. The bottle was placed in a freezer for approximately 1.5 hours to kill the insects. Each insect was then weighed and placed in 60 mL plastic bottles with known masses of deionized water (2 bottles with no insects, 2 bottles with 1 insect, 2 bottles with 2 insects each, and 2 bottles with 3 insects each). Water from the 60 mL bottles was removed 5 days later, filtered, and analyzed on the IC (Table A12-1).

The addition of the insects had no apparent affect on Na. There was a small affect on K (K concentration in water increased with the ratio of insect mass to water mass) and some effect (though not as large as K) on Ca and Mg (Figure A12-1). It should be noted that the insect-water mass in the experiment was much higher than in the bulk precipitation collector. Also, the insects generally found in the precipitation collector were not Cercopidae, rather they were smaller and thinner (more mosquito like) based on the observations of William Urena, the field technician who maintained the precipitation collector. The average water mass in the precipitation collector was 1,717 grams and taking insect masses equal to 1 and 3 Cercopidae (the latter probably an overestimate of insect mass in the precipitation collector) gives insect/water mass ratios of 8.9 e-6 to 2.3 e-4, suggesting the affect of insect contamination on the bulk rainfall sample chemistry is insignificant (even for K).

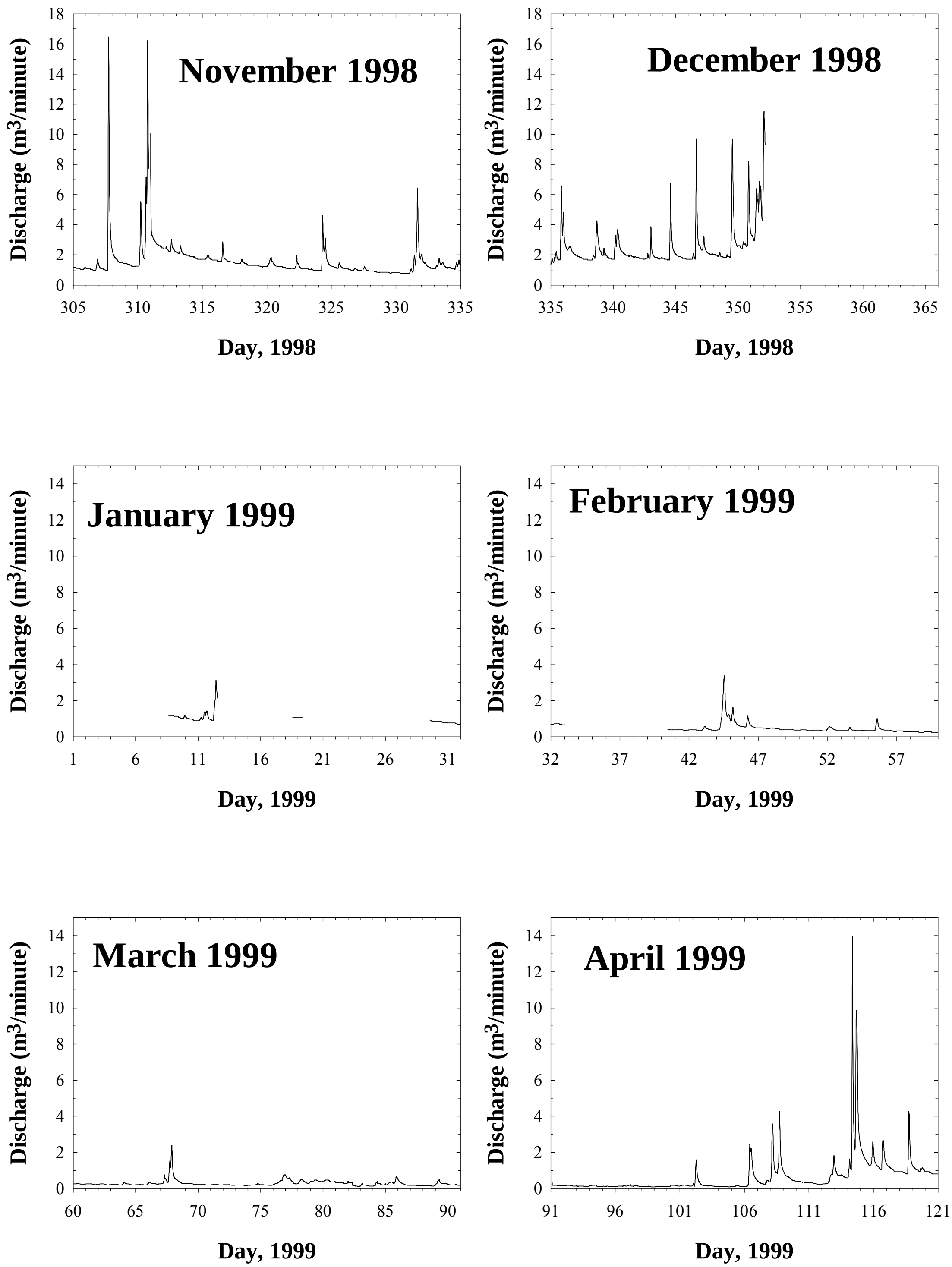
Table A12-1. Results of chemical analysis in mM of water samples containing varying amounts of insects.

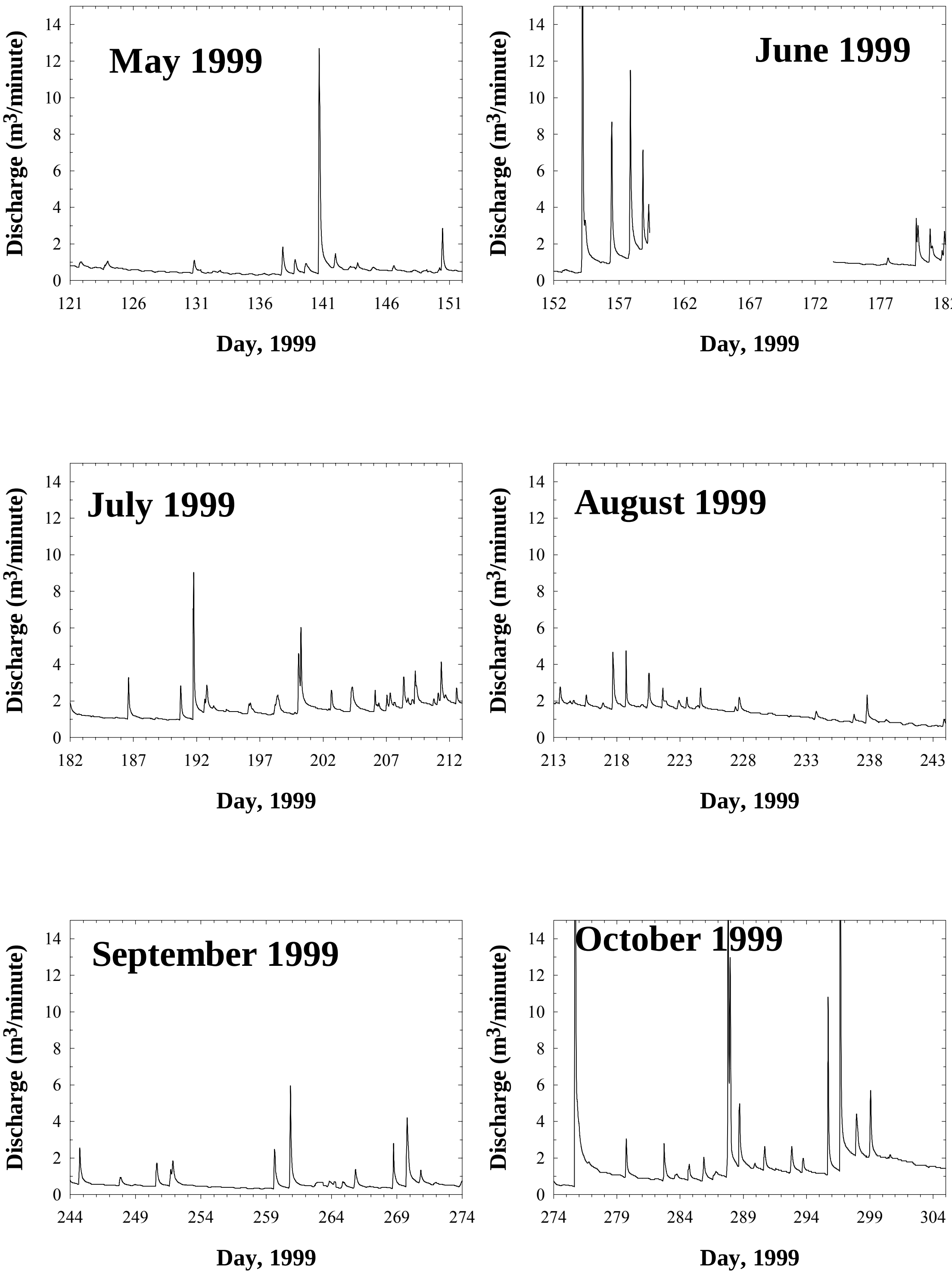
Bottle	Insect/ Water ratio	Na	K	Mg	Ca
No Insects					
1	0.00000	0.0044	0.0000	0.0000	0.0068
2	0.00000	0.0038	0.0000	0.0000	0.0000
One Insect					
3	0.00015	0.0025	0.0151	0.0103	0.0099
4	0.00009	0.0027	0.0094	0.0120	0.0112
Two Insects					
5	0.00022	0.0044	0.0212	0.0157	0.0119
6	0.00023	0.0042	0.0220	0.0142	0.0105
Three Insects					
7	0.000321	0.0039	0.0299	0.0205	0.0146
8	0.000299	0.0058	0.0288	0.0163	0.0075

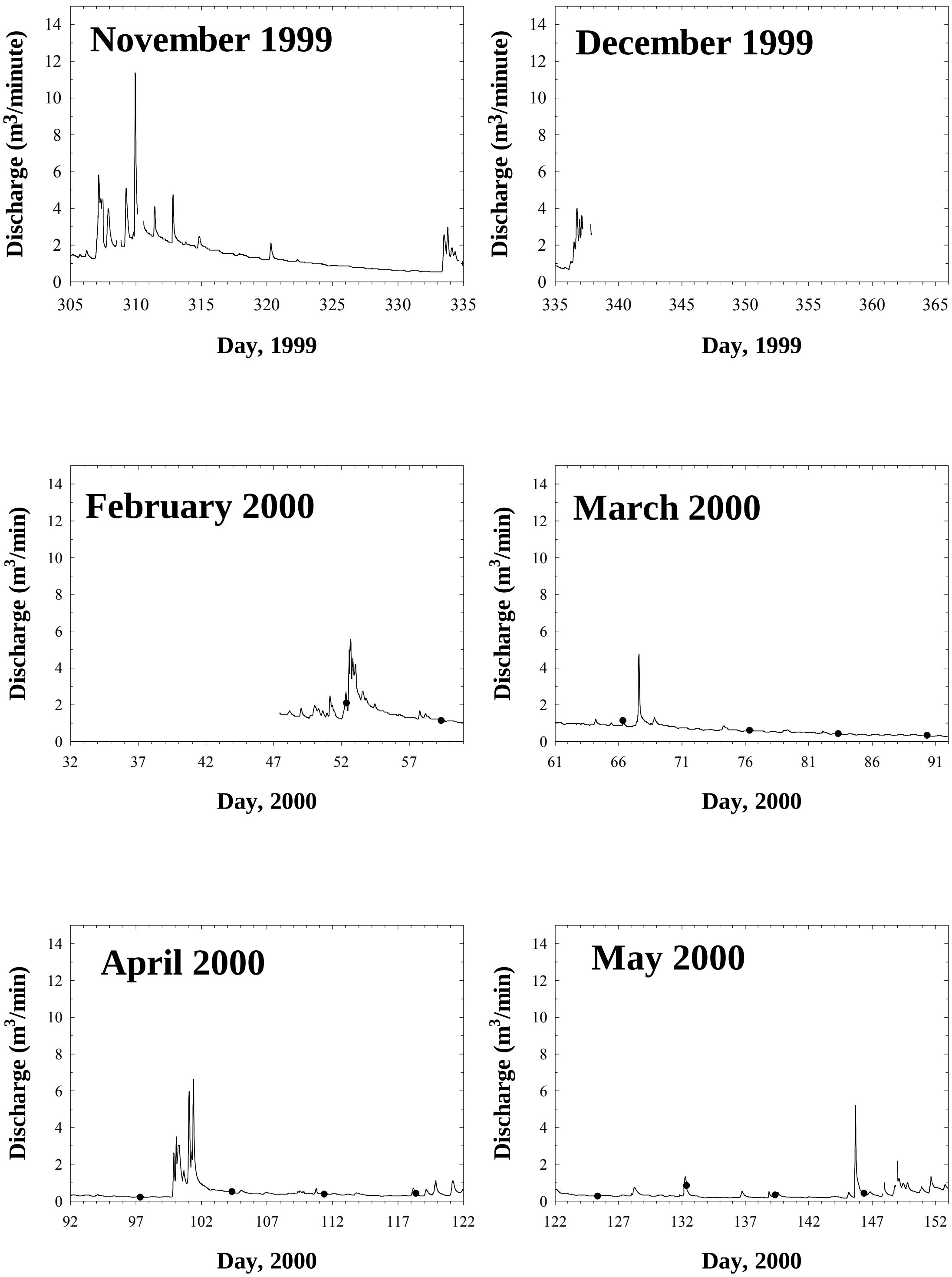
Figure A12-1. Plot of solute concentration against ratio of insect mass to water mass.

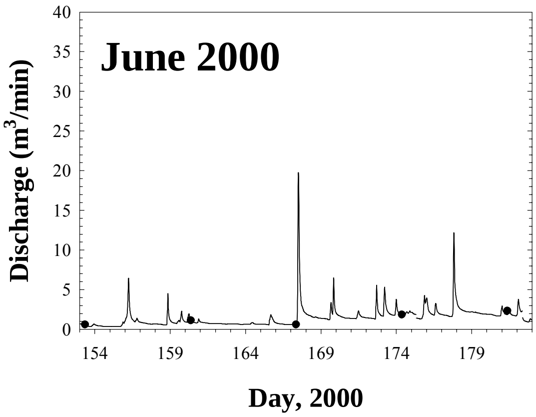


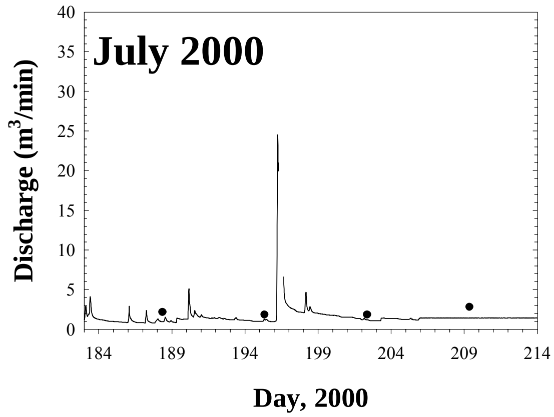
Appendix 13. Discharge (at the weir) versus time graphs for the Taconazo watershed. Manual staff gauge readings are shown as solid circles.

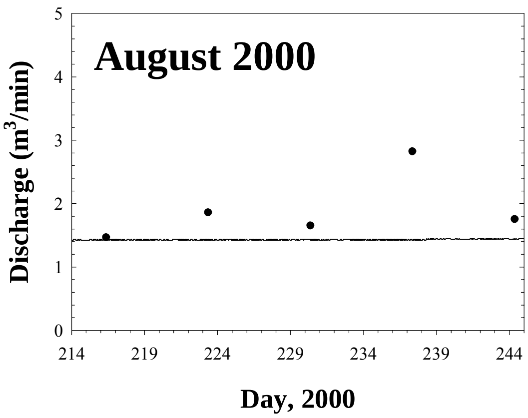


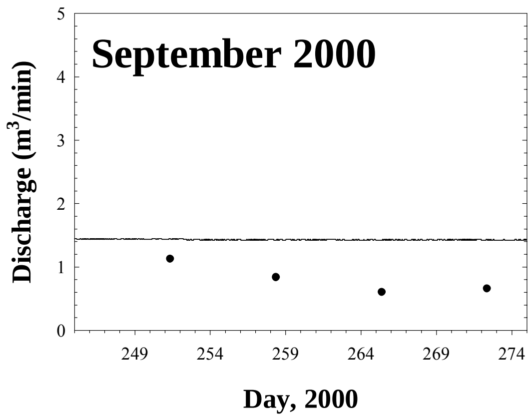

May 1999
June 1999
July 1999
August 1999
September 1999
October 1999
Discharge (m3/minute)
Day, 1999
0
2
4
6
8
10
12
14
121 126 131 136 141 146 151
152 157 162 167 172 177 182
182 187 192 197 202 207 212
213 218 223 228 233 238 243
244 249 254 259 264 269 274
274 279 284 289 294 299 304

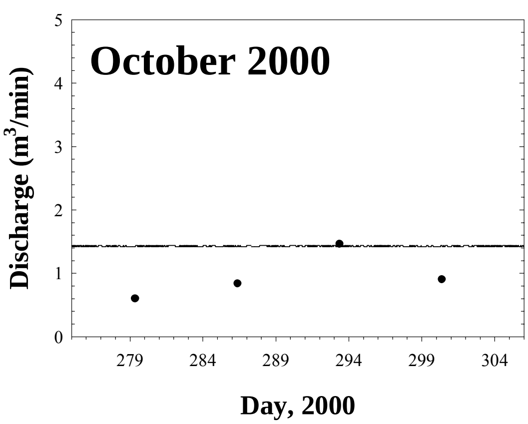

November 1999
Discharge (m3/minute)
Day, 1999
December 1999
Discharge (m3/minute)
Day, 1999
February 2000
Discharge (m3/min)
Day, 2000
March 2000
Discharge (m3/min)
Day, 2000
April 2000
Discharge (m3/min)
Day, 2000
May 2000
Discharge (m3/min)
Day, 2000

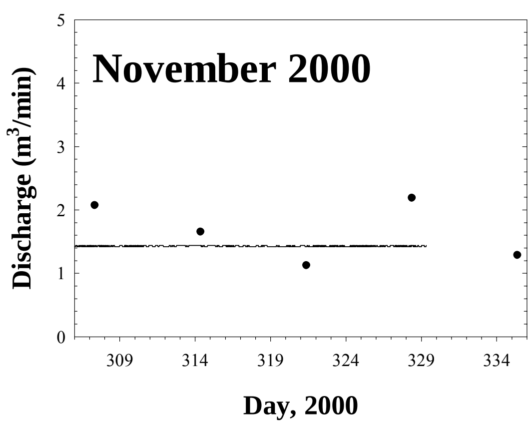

June 2000
Discharge (m3/min)
0
5
10
15
20
25
30
35
40
154
159
164
169
174
179
Day, 2000

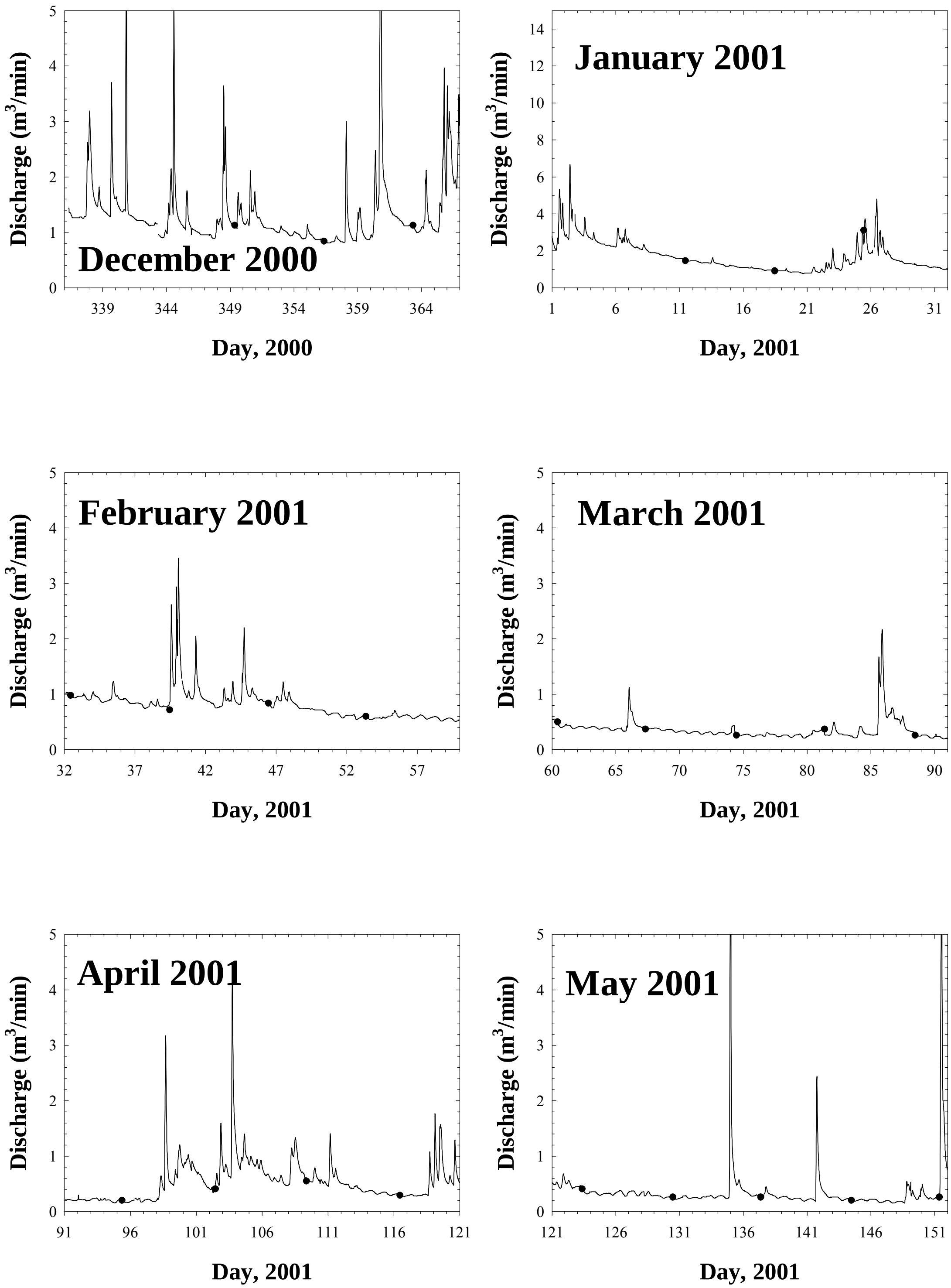

July 2000
Discharge (m3/min)
0
5
10
15
20
25
30
35
40
184
189
194
199
204
209
214
Day, 2000

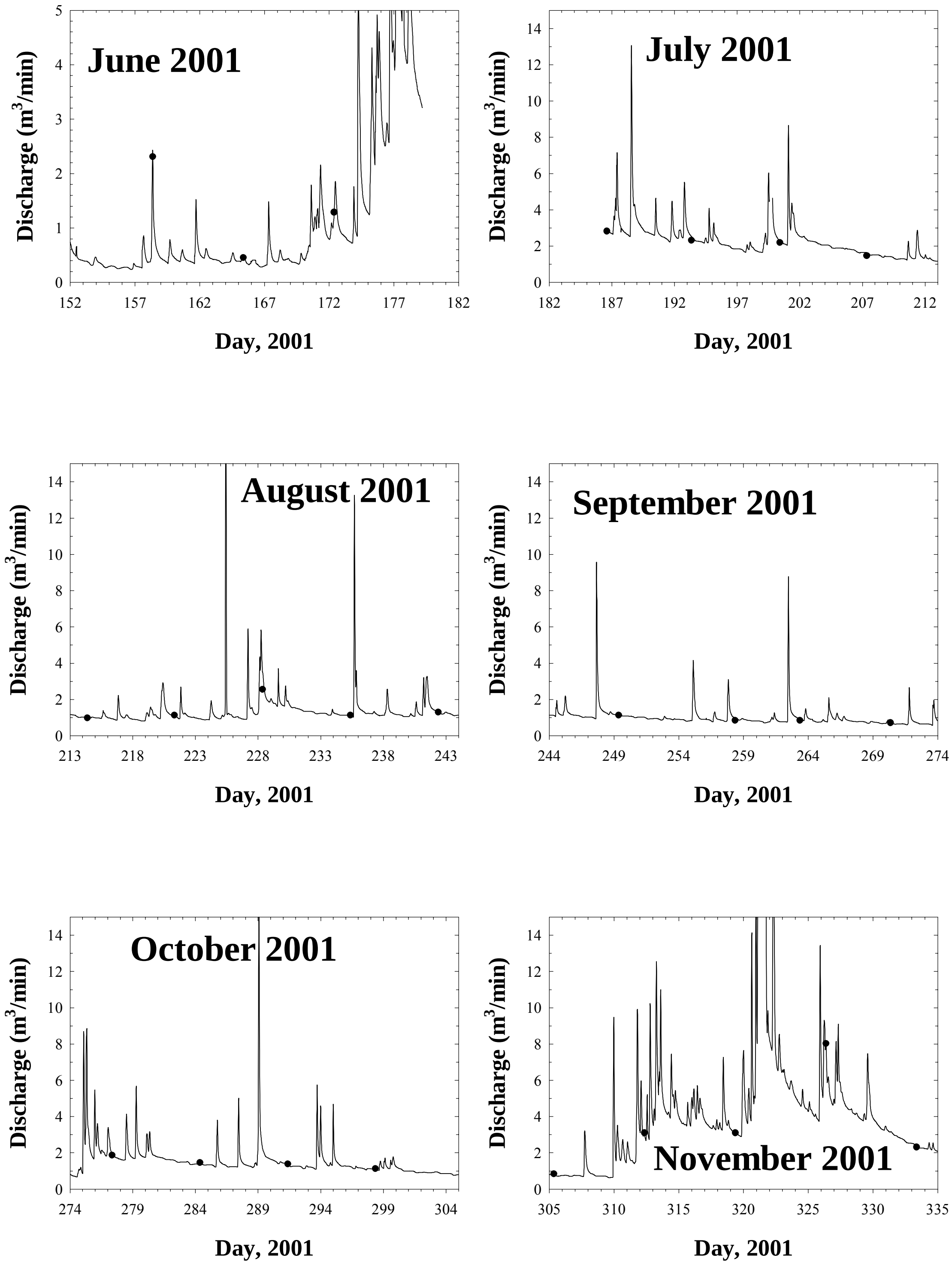

August 2000
Discharge (m3/min)
0
1
2
3
4
5
214
219
224
229
234
239
244
Day, 2000

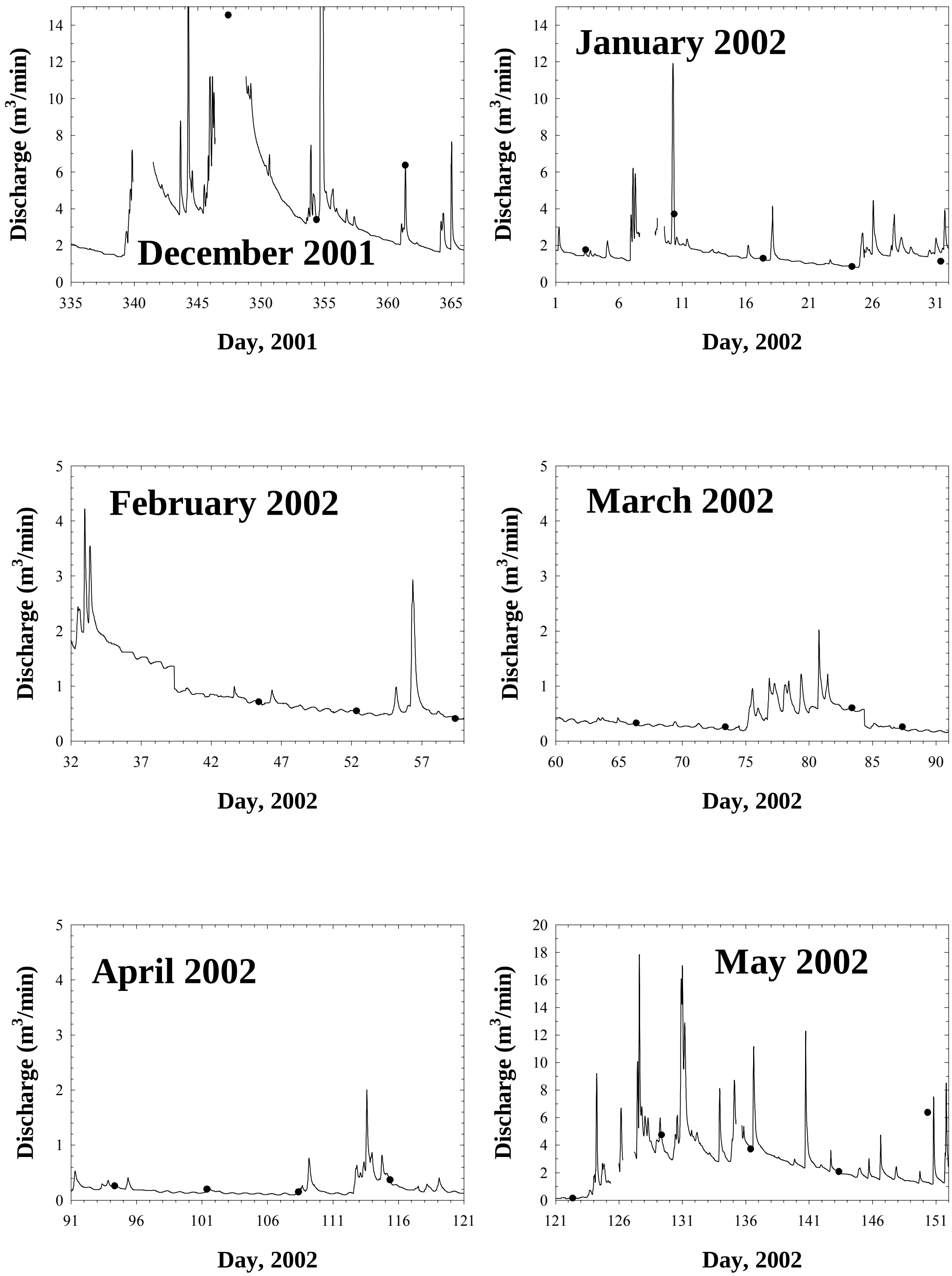

September 2000
Discharge (m3/min)
0
1
2
3
4
5
249
254
259
264
269
274
Day, 2000

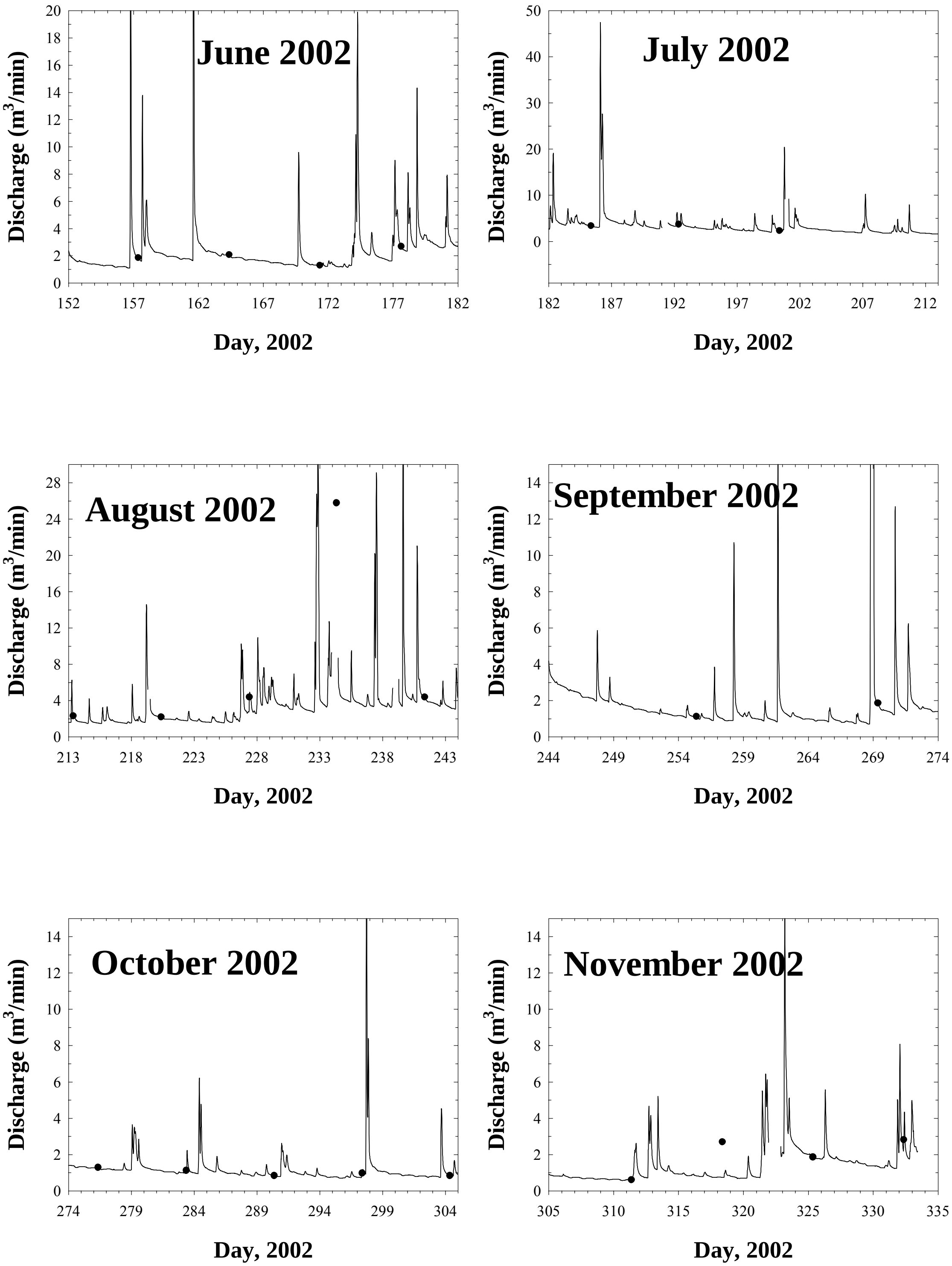

October 2000
Discharge (m3/min)
0
1
2
3
4
5
279
284
289
294
299
304
Day, 2000


November 2000
Discharge (m3/min)
0
1
2
3
4
5
309
314
319
324
329
334
Day, 2000

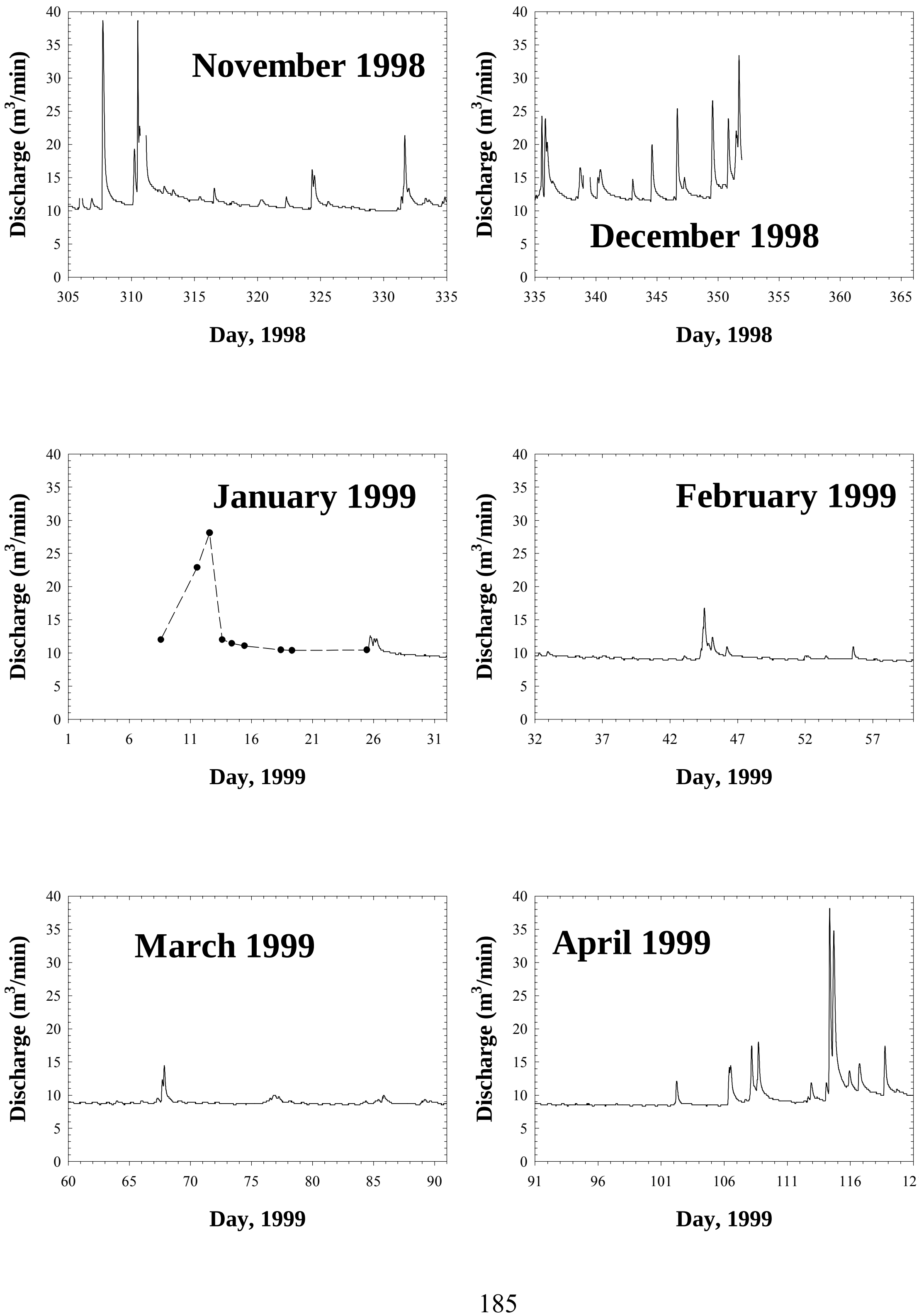

December 2000
Discharge (m3/min)
Day, 2000
January 2001
Discharge (m3/min)
Day, 2001
February 2001
Discharge (m3/min)
Day, 2001
March 2001
Discharge (m3/min)
Day, 2001
April 2001
Discharge (m3/min)
Day, 2001
May 2001
Discharge (m3/min)
Day, 2001

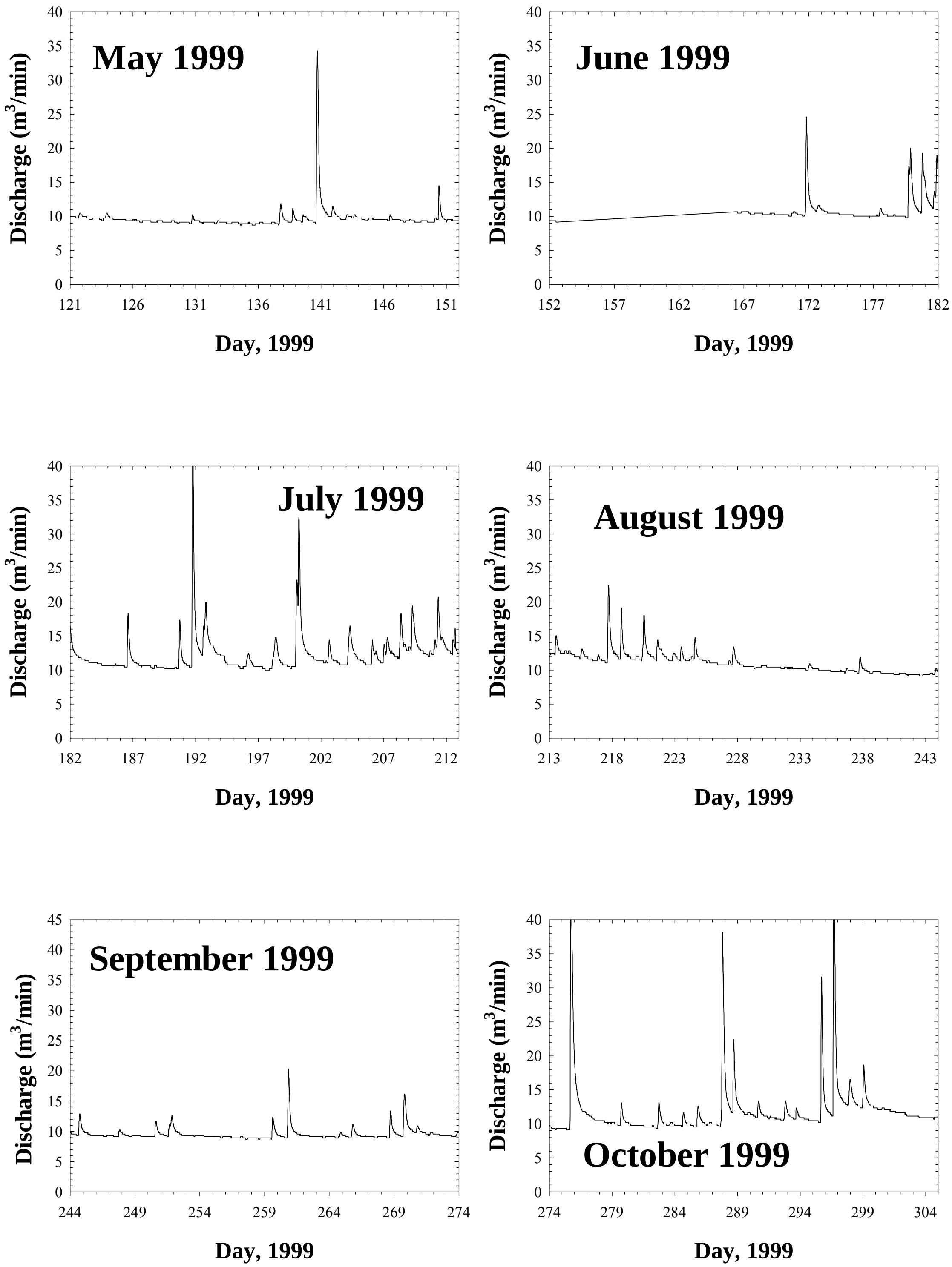

June 2001
July 2001
August 2001
September 2001
October 2001
November 2001
Discharge (m^3/min)
Day, 2001

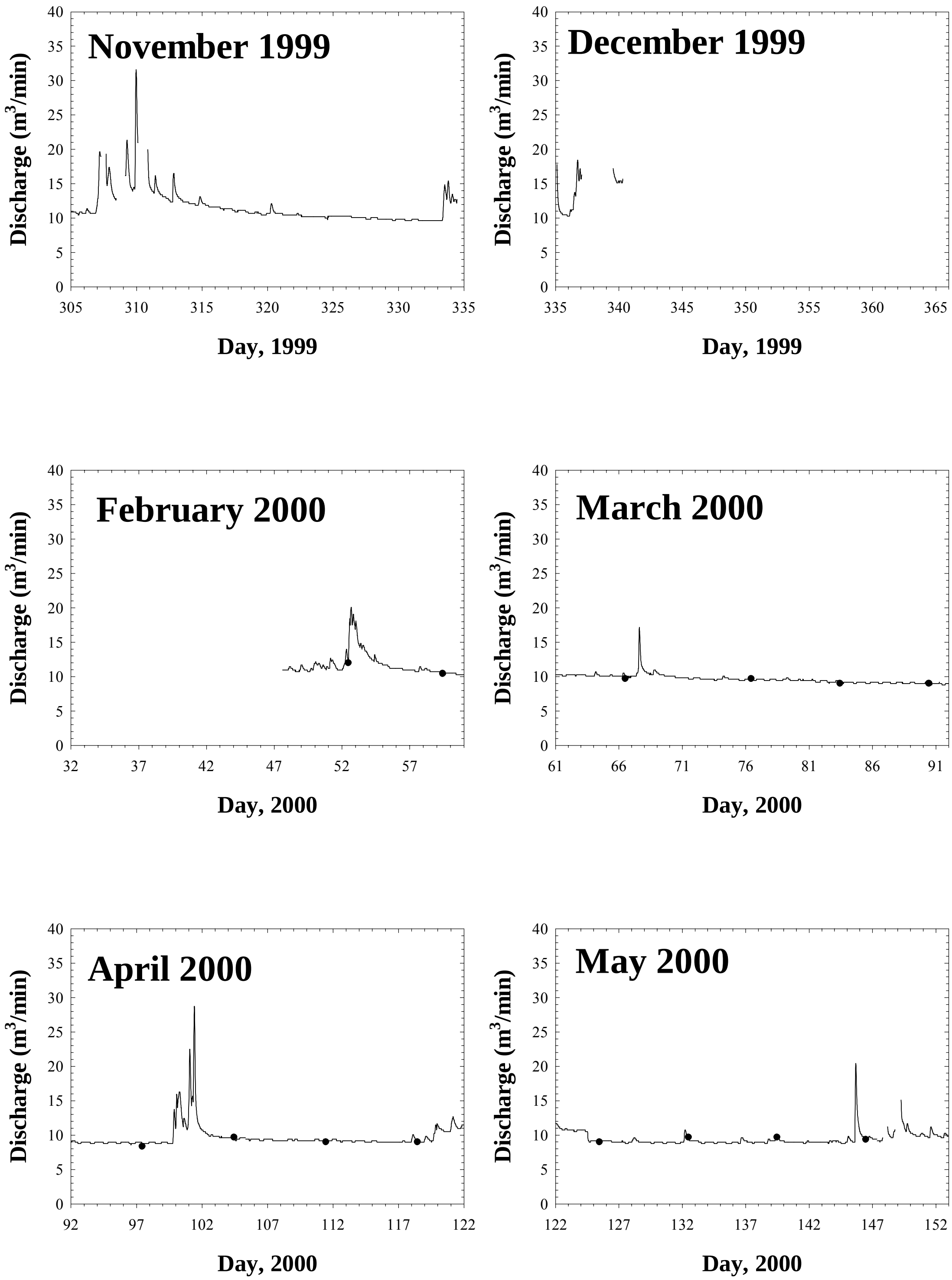

December 2001
Discharge (m3/min)
Day, 2001
January 2002
Discharge (m3/min)
Day, 2002
February 2002
Discharge (m3/min)
Day, 2002
March 2002
Discharge (m3/min)
Day, 2002
April 2002
Discharge (m3/min)
Day, 2002
May 2002
Discharge (m3/min)
Day, 2002

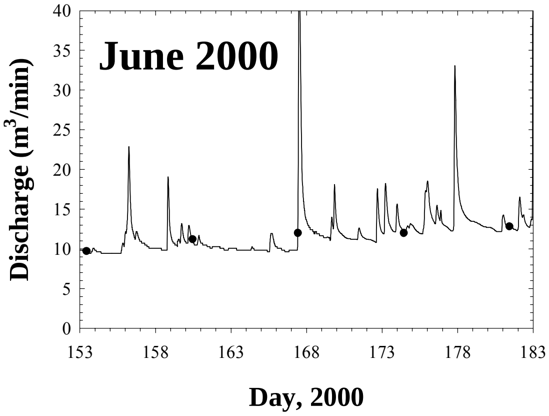

June 2002
July 2002
August 2002
September 2002
October 2002
November 2002
Discharge (m3/min)
Day, 2002

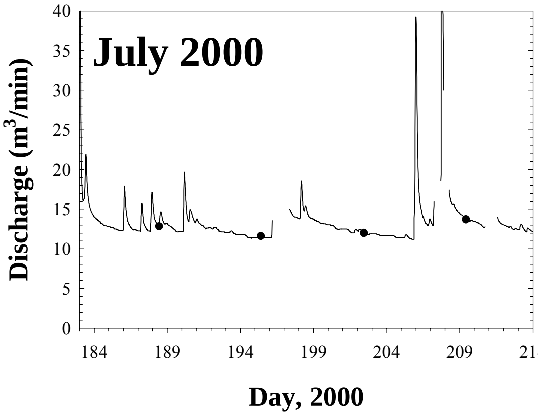
Appendix 14. Discharge (at the weir) versus time graphs for the Arboleda watershed. Manual staff gauge readings are shown as solid circles.

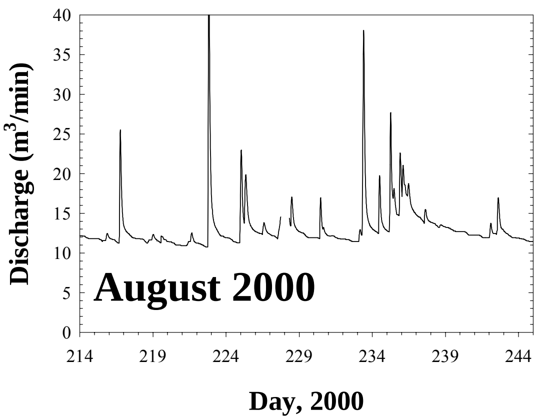


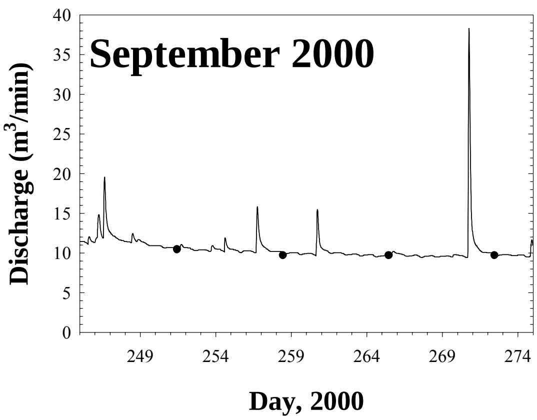

May 1999
June 1999
July 1999
August 1999
September 1999
October 1999
Discharge (m3/min)
Day, 1999
0
5
10
15
20
25
30
35
40
45
121
126
131
136
141
146
151
152
157
162
167
172
177
182
187
192
197
202
207
212
213
218
223
228
233
238
243
244
249
254
259
264
269
274
279
284
289
294
299
304

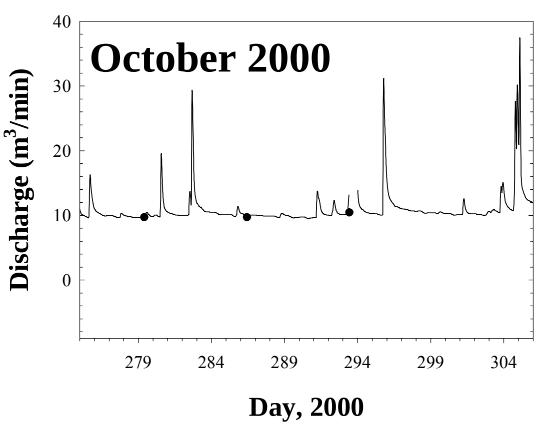

November 1999
December 1999
February 2000
March 2000
April 2000
May 2000
Discharge (m3/min)
Day, 1999
Day, 2000
0
5
10
15
20
25
30
35
40
305
310
315
320
325
330
335
340
345
350
355
360
365
32
37
42
47
52
57
61
66
71
76
81
86
91
92
97
102
107
112
117
122
127
132
137
142
147
152

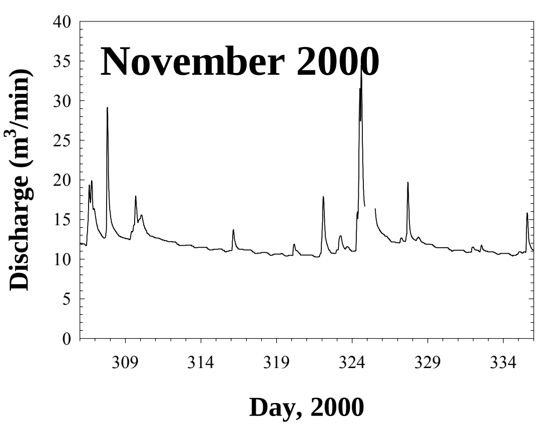

June 2000
Discharge (m³/min)
Day, 2000
0
5
10
15
20
25
30
35
40
153
158
163
168
173
178
183

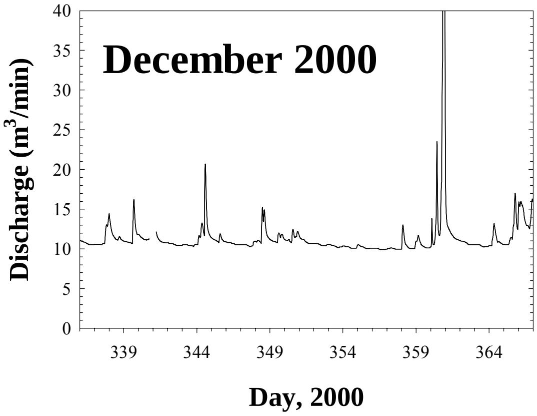

July 2000
Discharge (m³/min)
Day, 2000
0
5
10
15
20
25
30
35
40
184
189
194
199
204
209
214

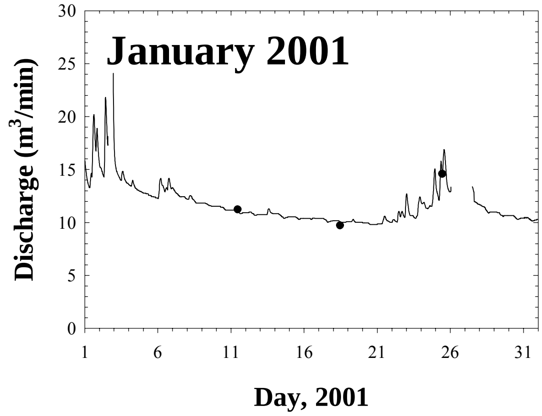

August 2000
Discharge (m³/min)
Day, 2000
0
5
10
15
20
25
30
35
40
214
219
224
229
234
239
244

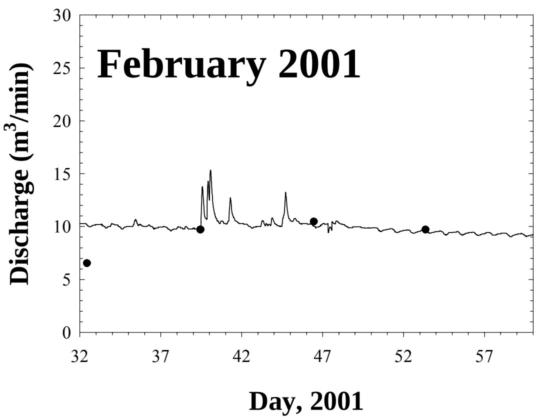

September 2000
Discharge (m³/min)
Day, 2000
0
5
10
15
20
25
30
35
40
249
254
259
264
269
274

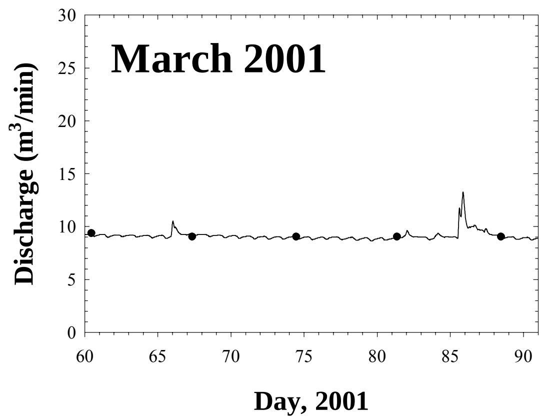

October 2000
Discharge (m³/min)
Day, 2000
0
10
20
30
40
279
284
289
294
299
304

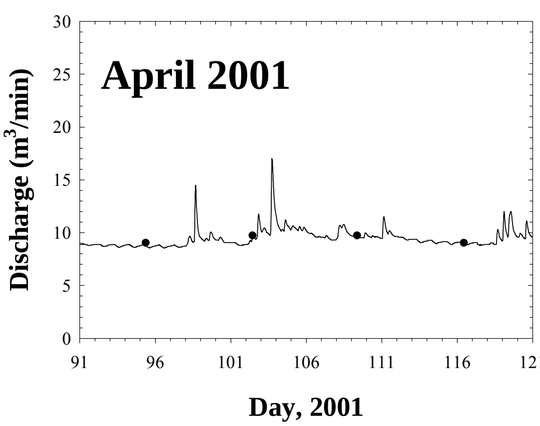

November 2000
Discharge (m³/min)
Day, 2000
0
5
10
15
20
25
30
35
40
309
314
319
324
329
334

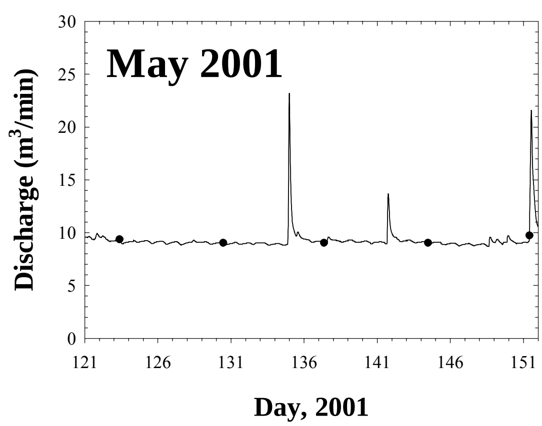

December 2000
Discharge (m3/min)
0
5
10
15
20
25
30
35
40
339
344
349
354
359
364
Day, 2000

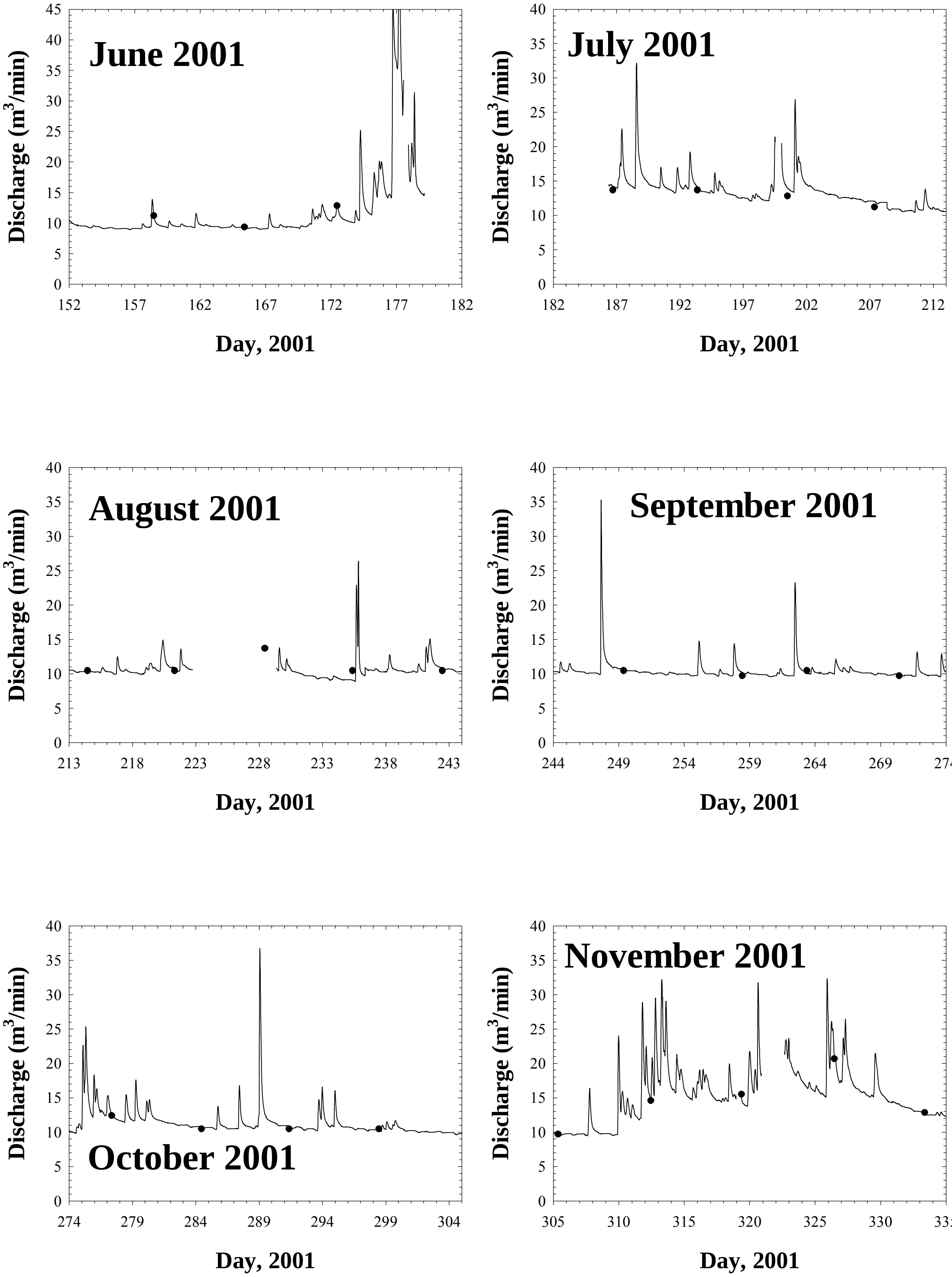

January 2001
Discharge (m3/min)
0
5
10
15
20
25
30
1
6
11
16
21
26
31
Day, 2001

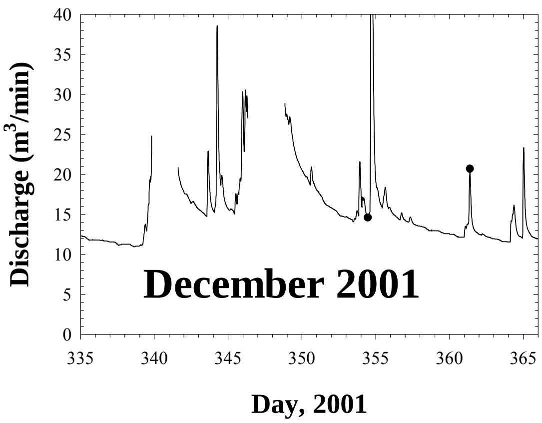

February 2001
Discharge (m3/min)
0
5
10
15
20
25
30
32
37
42
47
52
57
Day, 2001

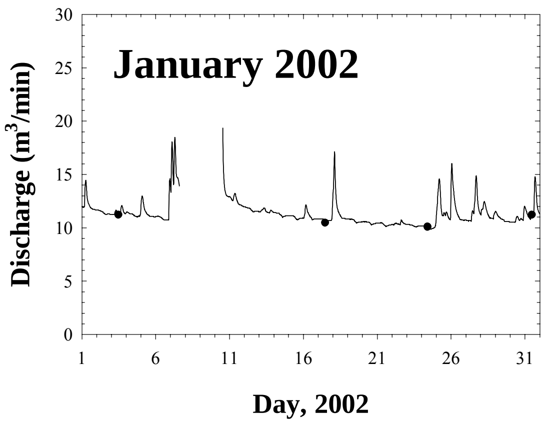

March 2001
Discharge (m3/min)
0
5
10
15
20
25
30
60
65
70
75
80
85
90
Day, 2001

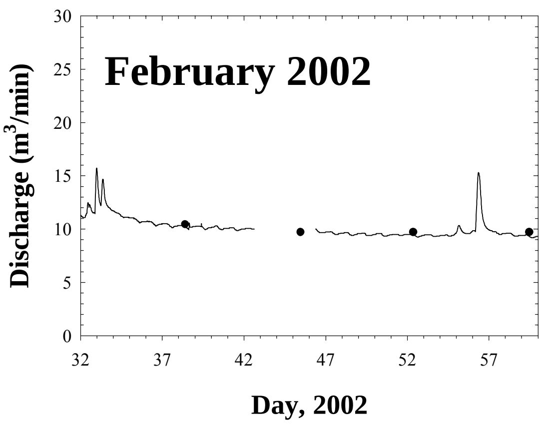

April 2001
Discharge (m3/min)
0
5
10
15
20
25
30
91
96
101
106
111
116
121
Day, 2001

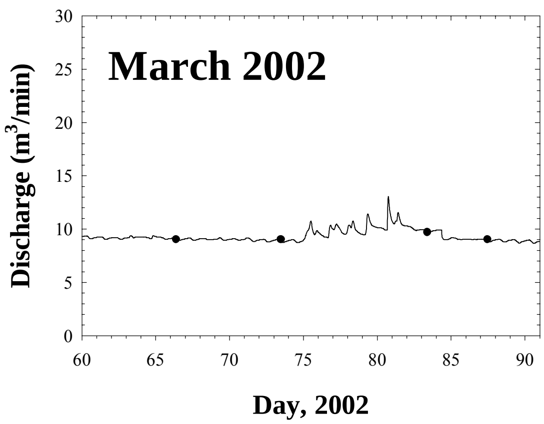

May 2001
Discharge (m3/min)
0
5
10
15
20
25
30
121
126
131
136
141
146
151
Day, 2001

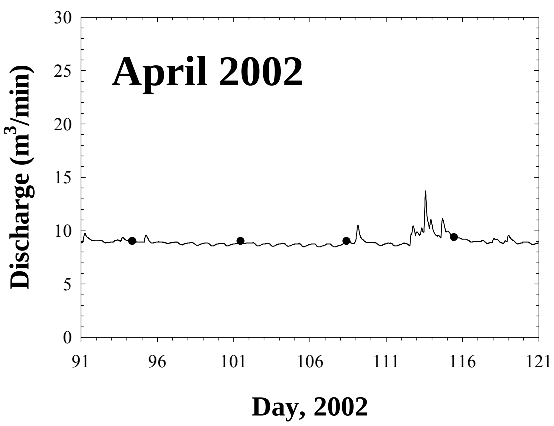

June 2001
Discharge (m^3/min)
Day, 2001
0 5 10 15 20 25 30 35 40 45
152 157 162 167 172 177 182
July 2001
Discharge (m^3/min)
Day, 2001
0 5 10 15 20 25 30 35 40
182 187 192 197 202 207 212
August 2001
Discharge (m^3/min)
Day, 2001
0 5 10 15 20 25 30 35 40
213 218 223 228 233 238 243
September 2001
Discharge (m^3/min)
Day, 2001
0 5 10 15 20 25 30 35 40
244 249 254 259 264 269 274
October 2001
Discharge (m^3/min)
Day, 2001
0 5 10 15 20 25 30 35 40
274 279 284 289 294 299 304
November 2001
Discharge (m^3/min)
Day, 2001
0 5 10 15 20 25 30 35 40
305 310 315 320 325 330 335

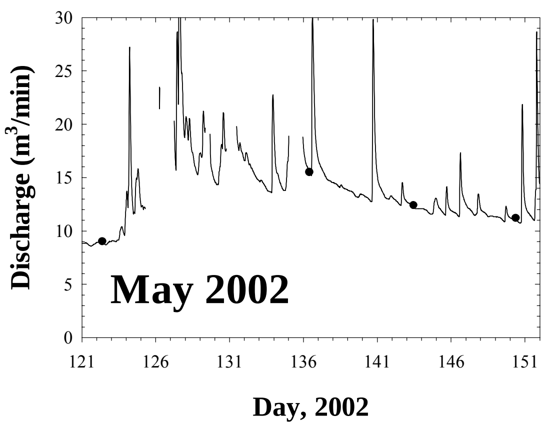

December 2001
Discharge (m3/min)
Day, 2001

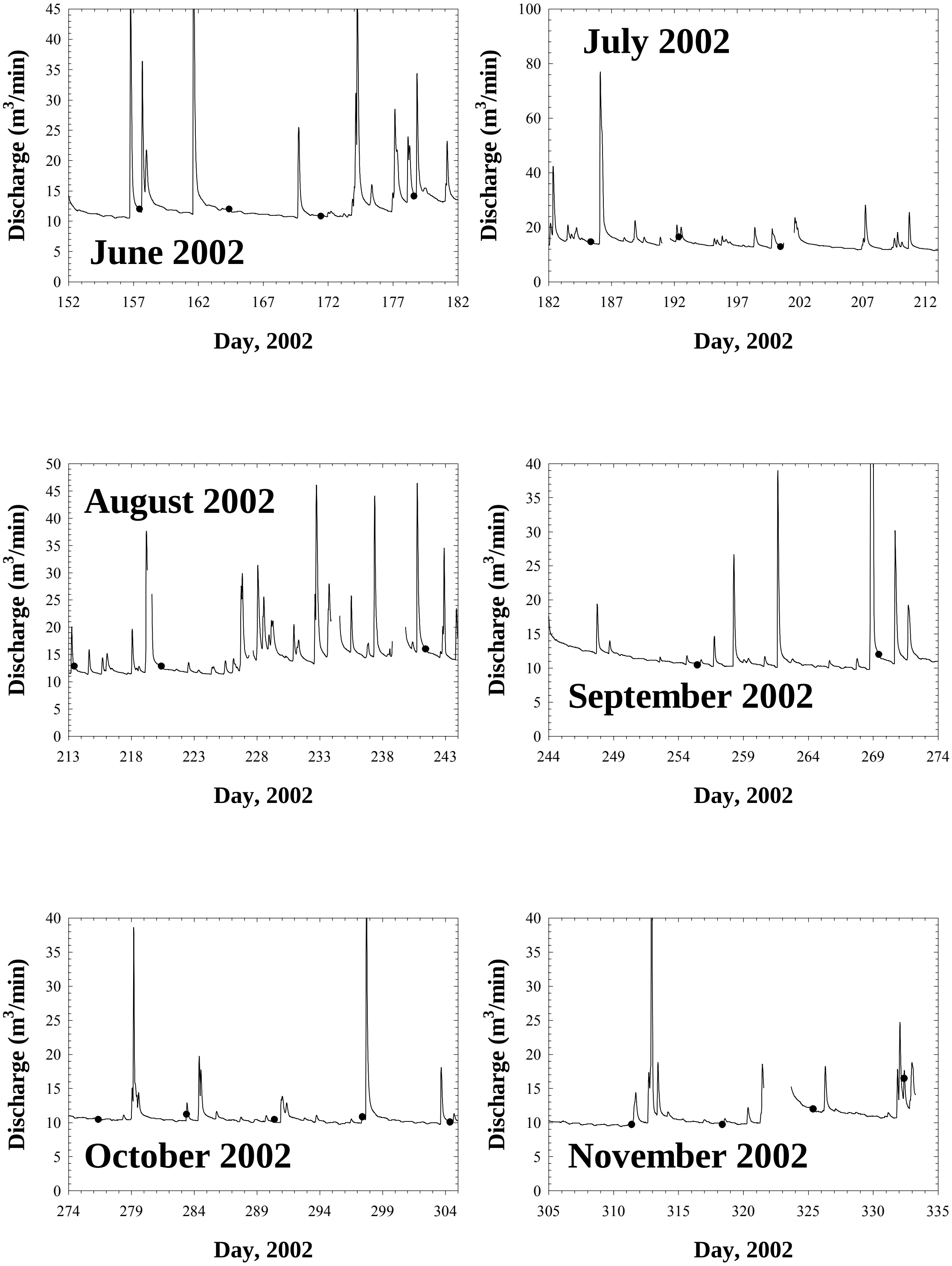

January 2002
Discharge (m3/min)
Day, 2002


February 2002
Discharge (m3/min)
Day, 2002


March 2002
Discharge (m3/min)
Day, 2002


April 2002
Discharge (m3/min)
Day, 2002


May 2002
Discharge (m3/min)
Day, 2002


June 2002
July 2002
August 2002
September 2002
October 2002
November 2002
Discharge (m3/min)
Day, 2002