The Riparian Ecosystem of South Boulder Creek: Hydrology, Vegetation and Restoration Opportunities

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ABSTRACT

Investigations were undertaken to examine the hydrology, vegetation and restoration opportunities of South Boulder Creek. The objectives of the study were (1) to investigate the interaction between the surface water and ground water of South Boulder Creek; (2) to relate these hydrologic conditions to existing riparian plant communities and (3) to use this information to evaluate the restoration potential of the system.

Water table profiles constructed from monitoring well data revealed gaining stream reaches, losing stream reaches and a combination of gaining and losing reaches. Several reaches also shifted from gaining in early summer to losing in late summer and fall. Results indicate the floodplain ground water and surface water of the stream are connected and interact.

Community classification was performed on vegetation plots centered on monitoring wells. This classification arranged study plots along a water table gradient illustrating the importance of the hydrologic regime in determining the species composition of these communities. The classification also showed most of the plant communities along South Boulder Creek are wetlands most likely supported by agricultural irrigation.

Restoration opportunities for the cottonwood/willow communities include restoring historic flows, creating sites conducive to cottonwood and willow germination and growth, planting and fencing. Each method is discussed.

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INTRODUCTION

Riparian areas are among the most biologically diverse and productive ecosystems in arid and semi-arid regions of western North America (National Research Council 1995). Although they comprise less than one percent of the land area in the western United States, they perform a number of important ecological functions and benefits. In their natural state, they support local and downstream food webs through allochthonous inputs (McArthur and Marzolf 1987, Brinson 1990), provide habitat for native insects, birds and mammals (Brinson et al. 1981, Knopf 1985, Snyder and Miller 1992), cycle nutrients (Brinson et al. 1980), improve water quality (Lowrance et al. 1985) and are important sources of biological diversity (Ohmart et al. 1988). Brown and Daniel (1991) detailed the aesthetic and recreational values of riparian areas.

Riparian ecosystems are also among the most impacted of western landscapes. Dam construction and the diversion of water for agricultural and municipal uses have resulted in dramatic alterations in the functions and processes of most western rivers and streams. Where dams have been constructed upstream from meandering stream reaches, lateral migration of the channel and the deposition of moist, bare sediment has been reduced or eliminated (Bradley and Smith 1986, Johnson 1992, Friedman et al. 1995). Because cottonwood and willow seeds require these conditions for germination, sexual reproduction of these species al. 1976, Scott et al. 1995). In addition, the diversion of water can lead to ground water declines and reduce water availability to riparian trees resulting in drought stress, reduced growth and increased mortality (Snyder and Miller 1991, Stromberg and Patten 1991).

Urban encroachment and the demand for outdoor recreational opportunities by a burgeoning population have subjected Colorado Front Range riparian areas to disturbance from hiking and biking trails and other human activities. Land use practices such as excessive livestock grazing have also been deleterious to riparian ecosystems (Hansen et al. 1988, Rood and Mahoney 1993). The consequences of these impacts include a decline in native woody riparian plant species, the invasion of aggressive non-native species such as Russian olive (Elaeagnus angustifolia (Christensen 1963, Teskey and Hinckley 1978, Knopf 1986, 1988) and the overall reduction in the width of floodplains to a narrow, often linear stream channel incapable of supporting riparian vegetation (Graf 1985). Colorado's plains cottonwood riparian forests are classified as critically endangered natural communities by the Colorado Natural Heritage Program (The Nature Conservancy 1995). A study of plains streams in Boulder County showed 60% of stream reaches bordered by riparian woodland. Of these, "good" structural diversity (defined as the presence of overstory and understory) or regeneration of riparian plant species occurred in only 30% (Boulder County Nature Association 1988).

Previous studies of riparian ecosystems have investigated the effect of flow alterations on channel dynamics (e.g., Johnson et al. 1976, Williams and Wolman 1984) or the relationship between surface flows and riparian vegetation (e.g., Stromberg and Patten 1990, Johnson 1994). The interaction between surface water and floodplain ground water and its effect on riparian vegetation is key to developing a detailed understanding of these systems (Rood and Mahoney 1993) although it has rarely been investigated. Several authors have shown that riparian trees rely on ground water as well as stream water for their survival and growth (Dawson and Ehleringer 1991, Busch et al. 1992). While studies of wildlife habitat and instream flow requirements for salmonids have been performed on South Boulder Creek, research on the surface water/ground water hydrology has never been conducted. An understanding of this interaction will be crucial to managing the riparian area of South Boulder Creek and evaluating its restoration potential.

The objectives of this study are (1) to investigate the interaction between the surface water and ground water of South Boulder Creek; (2) to relate these hydrologic conditions to existing riparian plant communities and (3) to use this information to evaluate the restoration potential of South Boulder Creek. Restoration is herein defined as establishing conditions that allow for natural or artificial recruitment of cottonwood and willow trees that will ultimately develop into cottonwood/willow communities.

The results of this study can be integrated with past and current Open Space research projects to develop an ecosystem approach to riparian restoration along South Boulder Creek and other streams in the Boulder area. This information will also contribute to the general knowledge and understanding of riparian ecosystems in the arid west.

STUDY AREA

South Boulder Creek originates along the Continental Divide in the Indian Peaks of the Southern Rocky Mountains. For approximately 40km it flows through the Colorado Front Range before entering the Boulder Valley through Eldorado Canyon. From Eldorado Springs, it flows northeast for 15km to its confluence with Boulder Creek east of the City of Boulder (Figure 1). South Boulder Creek drains a 324km^2 watershed and contributes approximately 40% of the flow of the Boulder Creek Basin.

South Boulder Creek is typical of many western North American streams that have been affected by water development and other land use practices. Its hydrologic regime has been altered by numerous diversion ditches and storage facilities that exist along its entire length. Constructed in the mid 1950's, Gross Reservoir is located on the mainstem of the stream 18km above the study area and is operated by the Denver Water Board. The Farmer's Reservoir and Irrigation Company (FRICO), currently the largest single water user, owns rights to approximately 25% of the surface water of South Boulder Creek and diverts water via the Community Ditch for agricultural and municipal use and for filling Marshall Reservoir. The Cities of Louisville and Lafayette obtain all of their municipal water from the stream. The City of Boulder and Public Service Company of Colorado also own surface water rights to South Boulder Creek. The Colorado State Engineer has operated a gauging station above Eldorado Springs since 1896.

The study area is on City of Boulder Open Space property along South Boulder Creek from north of the town of Marshall to Baseline Road (ca. 39°58'N, 105°14'W)(Figure 2). The elevation ranges from 1648 m at the south end of the study area to 1610 m at the north end where the stream has a constant and gentle gradient of .009 m/m. A natural surface trail parallels the stream through the entire study area. This trail is one of the heaviest used trails within the Open Space system receiving ca. 250,000 visitors per year. The riparian area is managed for its natural values as well as for recreation and historic agricultural practices such as grazing and hay production.

The study area lies within the Colorado Piedmont section of the Great Plains Physiographic Province (Madole 1991). The climate is continental with cold winters and warm summers. Mean annual precipitation is approximately 47cm (Colorado Climate Center 1992). Niwot Series soils predominate on the low terraces and bottoms along the stream where they formed in loamy alluvium

(Moreland and Moreland 1975). These soils are shallow and overlie unconsolidated cobble, gravel and sand. Bedrock consists of 2438 m deep Pierre shale.

Land use practices such as livestock grazing, channelization and urban development have likely impacted cottonwood and willow germination and survival. In the study area, the cottonwood/willow community is comprised mostly of old trees with very few individuals representative of young age classes (pers. observ.). Where young trees are observed, the cottonwoods are sprouts from the exposed roots of older trees and the willows are non-native crack willows (*Salix fragilis*) that have grown from branches that have broken from older trees and sprouted in moist soil.

METHODS

Transects were established to investigate surface water/ground water interactions and to relate environmental factors, including hydrology, to different riparian plant communities. Transects allow elevational profiles of surface water and ground water to be constructed to help understand the direction of water flow. Study transects were not randomly chosen but were selected based on vegetation type, historic and current land use practices, channel impacts and physical constraints imposed on monitoring well installation. However, most of the major community types of this section of South Boulder Creek observed during pre-research visits were represented in the study population. Transects were oriented perpendicular to the stream channel and were numbered 1 (north) through 5 (south).

Circular plots 4m in radius ($50m^2$) were located along each transect, where all data and observations were taken. Each plot was centered on a ground water monitoring well. The coarse, cobbly alluvium of the study area soils necessitated the use of a truck mounted soil auger for monitoring well installation. Because of access limitations imposed by irrigation ditches and steep terrain, a complete transect spanning both sides of the stream could not be established at transect 4 and wells were installed only on the west side of the stream in this location. Only one monitoring well on each side of the stream was installed along transect 1 for the same reasons.

Monitoring wells were cased with 5.08cm diameter machine slotted pvc pipe on the bottom half coupled to solid pipe on the top and capped on the bottom. Wells were installed at least 30cm below ground water levels at the time wells werer installed. Where each transect crossed the stream, a 0.64cm diameter staff gauge 1.2m long was installed in the thalweg. Wells and staff gauges were surveyed for elevation and their approximate positions were located on aerial photographs. Transects, plots and wells were installed in April 1995. Locations of monitoring wells and transects are shown in Figures 4A-C.

Wells and staff gauges were monitored ca. weekly from May through October to measure depth to the water table and electrical conductivity (EC). Water samples from the monitoring wells and stream were collected in late September and analyzed for major cations and anions using standard methods by the City of Boulder Water Quality Lab. Historic and current streamflow data was compiled from the gauging station above Eldorado Springs.

In early September, all plant species in the vegetation plots were identified and their percent cover estimated by Daubenmire cover classes (Mueller-Dombois and Ellenberg 1974). Plant nomenclature follows Weber (1990).

RESULTS

A comparison of peak summer flows (May through August) from the Eldorado Springs gauging station before and after Gross Reservoir began operation shows a significant reduction (Mann-Whitney rank sum test, $p=0.005$, $\alpha=0.05$) in flow as a result of upstream diversions and impoundments (Figure 3). Base flows were not significantly different (Mann-Whitney rank sum test, $p=0.089$, $\alpha=0.05$). Diversions between the Eldorado Springs gauge and the study area (e.g., Community, Davidson and Goodhue ditches) reduce flows substantially more but are not reflected in the gauge record. Because cottonwood and willow establishment and growth are closely coupled with a stream's hydrologic regime, stream flow alterations can cause dramatic changes in the diversity and structure of riparian plant communities (Bradley and Smith 1986, Rood and Mahoney 1990, Scott et al. 1993).

1995 was the wettest year on record for Boulder (NOAA 1995). Abundant rainfall in the spring and summer combined with record snowfall in the South Boulder Creek watershed during the winter of 1994-1995 contributed to above average streamflow and flooding on South Boulder Creek. Streamflow data from the Eldorado Springs gauge show several above average peaks, the most notable of which was a mean daily flow of 21.5 cubic meters per second (cms) on 18 June. Flows of this magnitude represent a hydrologic event that occurs approximately once every 15 years. This mean daily flow is more than twice the long-term (1896-1994) average mean daily flow of 9.2cms (Figure 5).

As a result of record precipitation, some of the hydrologic data collected during this study may not be indicative of long-term conditions. Water tables reported as being close to the ground surface in certain wells this year may actually be well below the ground surface during "average" water years. However, data collected in late summer was presumed to be past the influence of the spring and early summer flooding and more representative of typical hydrologic conditions of the system.

Riparian landscape positions along South Boulder Creek that are usually beyond the influence of annual flooding were flooded this season. For example, the terrace where monitoring wells 1-

10 are located normally has a water table close to the ground surface during peak stream stage. However, it is high above the stream channel and shows no evidence of recent or frequent flooding such as surface scouring, sediment deposition or water borne debris. On 18 June, 1995, South Boulder Creek overtopped it's bank at the south staff gauge and flowed across this terrace (Figure 6). A similar flooding event occurred on this date at Transect 2 (Figure 7).

SURFACE WATER/GROUND WATER RELATIONSHIPS

To investigate the relationship between the surface water of South Boulder Creek and the floodplain groundwater, and to examine the association between plant communities and hydrology, profiles were constructed of water table elevations along transects on different sampling dates. These profiles helped to determine if and when a particular stream segment was gaining (i.e., stream receiving ground water) or losing (stream flow contributing to ground water).

The staff gauge in the stream at Transect 1 was lost twice before it could be surveyed for elevation (once by high flows and once by vandals). As a result, ground water/surface water relationships could not be constructed for this transect.

The stream segment traversed by Transect 2 gains ground water from the east and loses to the ground water on the west. During the entire period of record, the water table at well 24 was higher than the surface water in the stream indicating a gaining situation. Although this gain may be supported early in the summer by irrigation water from the meadow east of well 24, late summer water tables (e.g., after irrigation ended) remained high. Water chemistry data from wells 24 and 25 show similar chemical compositions further supporting a connection (Appendix 1).

The water table at well 27 was always lower than the surface water in the stream indicating that the stream contributed to the ground water on the west side of the stream (Figure 7). The deep water table west of the stream may be influenced by the created mitigation wetland ca. 20m west of well 27. The ground surface in the wetland is several meters lower than the ground surface at well 27 possibly lowering the water table.

Transect 3 is located where the stream shifts from a gaining stream early in the season to a losing stream late in the season (Figure 8). For example, on 26 May and 14 June, the stream gained groundwater from both the east and west. On 3 July and 24 October, the stream lost water to the surrounding ground water on both sides of the stream. This shift from a gaining to a losing reach may be due to irrigation in the meadows at the east and west ends of this transect. During extreme flood events such as occurred on 18 and 19 June, the floodplain groundwater contributed to the stream from the west and the stream lost water to the east.

Because the east side of the stream could not be accessed with the truck mounted auger, Transect 4 covers only the west side of the stream. The west side of the stream exhibits a pattern similar to that of transect 3 in that it shifts from a gaining stream early in the season to a losing stream late in the season (Figure 9). On 18 May and 5 June, the stream gained ground water. In mid July and late August, the stream lost water to an area under monitoring well 16 which also receives groundwater from the west. Monitoring well 16 is located in an abandoned channel of South Boulder Creek that apparently still acts as a conduit for streamflow and ground water.

Transect 5 shows a gaining stream reach for much of the year. From late May through August, the stream gains ground water from both sides of the stream (Figure 10). In October, the stream is still gaining from the east but has begun to lose water to the west.

VEGETATION CLASSIFICATION

Vegetation in the 28 plots was classified using "two way indicator species analysis" (TWINSPAN), a divisive hierarchical classification technique (Hill 1979). The goal of this method is to derive groups of plots with similar vegetation composition which can then be used to develop an objective vegetation classification. From this, environmental factors can be analyzed to interpret which are most related to vegetation similarities and dissimilarities.

In general, the analysis separated stands with trees from stands without trees in the first series of divisions (Figure 11). Wetter stands (i.e., stands with plants able to tolerate a high water table) were then separated from drier stands.

The first level of division in the data is between stands with cottonwoods and all other stands. The cottonwood stands have overstories of *Populus deltoides* and/or *Populus angustifolia* and understories of *Dactylis glomerata* and *Arctium minus*, and are represented by plots 20 and 28. The second level of division separates the only other stand with a dominance of woody species from the remaining stands with herbaceous species. Plot 30 is dominated by *Alnus tenuifolia* with and understory of *Calamagrostis inexpansa* and *Carex emoryi*.

It is clear from these first two division that a site's hydrologic regime, particularly the period of inundation and the development of anaerobic conditions in the soil, is the most important environmental factor determining the composition of vegetation in the study. Whereas plots 20 and 28 had a water table a meter or more below the ground surface for much of the season, plots 30 exhibited a water table less than 50cm below the ground for the entire study period.

The third level of division in the data splits the remaining stands, all of which are dominated by herbaceous species, into those with a high water table dominated by *Spartina pectinata*, *Agrostis stolonifera* and several species of *Carex*, and those with deeper water tables dominated by *Juncus arcticus, Dactylis glomerata, Panicum virgatum* and *Andropogon gerardii*. Although *Juncus arcticus* is typically found in wetland communities, it is capable of persisting in former wetlands or wet meadows that are not wetlands. The drier groups of stands are remnants of tallgrass prairie communities that may once have been more common along South Boulder Creek than today. The best examples of wetland stands include those around plots 1, 4, 19 and 25 while plots 10A, 11 and 27 are representative of the drier communities. Again, it is clear that a sites hydrology is an important determinant of the floristic composition of these plots.

A final, albeit less distinct, division in the data set separates the wettest wetland stands with *Carex nebraskensis*, *Carex bebbii* and *Eleocharis palustris* from drier wetland stands containing *Spartina pectinata* and *Agrostis stolonifera*. Although this division is not as distinct as the previous ones, it is an important division none-the-less. Stands dominated by the *Carex* species and *Eleocharis palustris* have permanently saturated and reducing soil conditions while stands dominated by *Spartina* and *Agrostis* have seasonally saturated soils that are occasionally aerobic.

This community classification illustrates the importance of the hydrologic regime in determining the species composition of communities in this study. The stands represented by the study plots are arranged along a water table gradient even though divisions occur between woody and herbaceous species and between different types of herbaceous wetland species. The classification dendrogram produced from TWINSPAN data is illustrated in Figure 11.

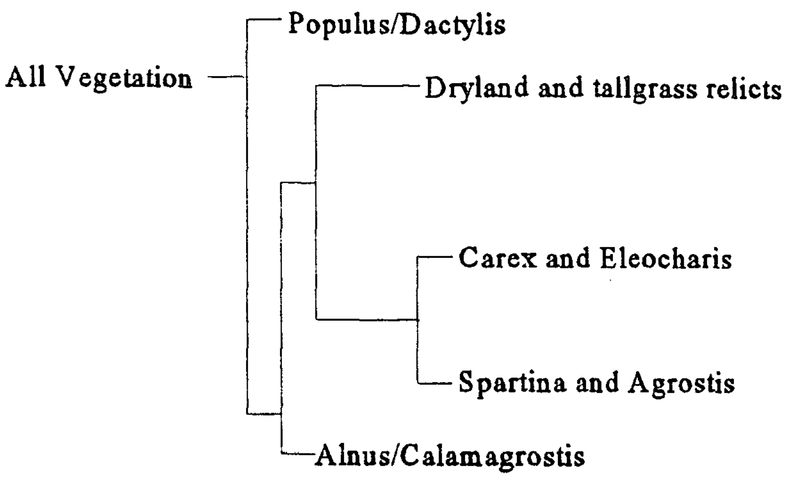

Figure 11. TWINSPAN classification of study plots on South Boulder Creek.

DISCUSSION

Results of the hydrologic investigations show the ground water of the South Boulder Creek floodplain and the surface water in the stream are connected and appear to interact. At times the stream contributes water to the floodplain ground water and at other times the ground water feeds the stream. This interaction is evident even in late summer when the effects of this years high water and agricultural irrigation are no longer factors.

Historically the interaction between the floodplain and surface water of South Boulder Creek was probably greater due to more frequent and severe floods. These high flows would flood the terraces and spread out on the floodplain depositing nutrient laden sediments and organic matter. Flood waters would also erode the outside meanders of the stream and deposit alluvium on the inside of meanders.

Aerial photographs of South Boulder Creek in 1937 show a sinuous stream channel occupying a broader floodplain than today. The regulation of flows has likely reduced the meander rate and subsequent development of alluvial deposits necessary for the establishment and growth of cottonwoods and willows. There appears to be evidence of this occurring on South Boulder Creek although this was not researched directly in this study. The lack of recently created alluvial surfaces and young age class stands of cottonwoods and willows on most of the stream suggests that much of the dynamic fluvial processes of South Boulder Creek no longer occur. Negative impacts to riparian forests below dams as a result of the effects of declining river meander rates have been well documented (Johnson et al. 1976, Fenner et al. 1985, Rood and Mahoney 1990, Johnson 1992, Scott et al. 1995).

The interaction between surface water and ground water that was largely driven by high flows and overbank flooding in the past is now supported by flood irrigation practices in the meadows along South Boulder Creek. Although irrigation distributes water across the floodplain and maintains wetland plant communities, it is very different than overbank flooding.

If severe enough, high flows that cause stream water to flow across the landscape carry with it nutrients for plants and invertebrates. In addition, disturbance is created by erosion and deposition of alluvium allowing early successional cottonwood and willow forest types to persist. An intermediate level of disturbance associated with flooding has been shown to increase species richness and diversity in riparian forests (Stromberg et al. 1991).

The previous discussion assumes a model of riparian tree ecology driven by sexual reproduction and seedling establishment on recently deposited sediment from high stream flows. This model has been suggested for Boulder Creek (Friedman et al. 1995) and other streams and rivers in the arid west (Bradley and Smith 1986, Snyder and Miller 1991, Johnson 1992). However, Rood and Mahoney (1993) suggest that asexual recruitment in the form of suckering and coppicing is extensive and may even be the dominant form of reproduction in some systems (see Krasney et al. 1988, Irvine and West 1979). It may be particularly important along foothill type rivers with coarse substrate such as South Boulder Creek. Further research is needed to understand the contributions of these two models to riparian forests on South Boulder Creek.

The hydrologic data and community classification suggest that many of the sites on the floodplain of SBC are not suitable for cottonwood and willow establishment or growth. Some sites are too wet because flood irrigation creates anaerobic soils that adult cottonwoods and willows are unable to grow in. Examples of this can be seen at plots 1, 4, 18, 19, and 24. Other sites are too high above the water table to permit seeds to germinate or seedlings to grow and are also beyond the influence of flooding, including plots 10A, 10B, 11 and 27.

Riparian Restoration Opportunities

Restoration opportunities for the cottonwood\willow communities of South Boulder Creek include; (1) restoring historic natural flows; (2) creating sites conducive to cottonwood and willow germination; (3) planting and (4) fencing.

Recent research has suggested that the most important factor leading to the decline of cottonwood/willow communities on formerly meandering streams downstream of dams is the reduction in the formation of bare, moist sediment deposits suitable for seed germination (Rood and Mahoney 1990, Johnson 1992, Friedman et al. 1995, Scott et al. 1995). If this is the correct model for South Boulder Creek, restoring historic flows could allow the stream to meander and form alluvial bars. Floods would be timed to coincide with seed fall and allow seeds of cottonwoods and willows to germinate on these surfaces.

Although this method would likely restore the greatest number of ecosystem functions to the floodplain, it is unlikely to be implemented for several reasons. As discussed above, most of the water is "owned" by a number of entities whose cooperation and long-term commitment to contribute water would be needed in order to maintain natural flows. In addition, urban development has occurred on the floodplain upstream and downstream of the study site. Restoring flows of the magnitude needed to allow channel migration to occur could cause damage to and loss of property.

Artificially creating bare, moist sites conducive to the germination and growth of cottonwoods and willows is another possible technique that could be used to restore and maintain riparian forest communities along South Boulder Creek. This involves removing sod from floodplain sites when seedfall from cottonwoods and willows is occurring and irrigating the disturbed surface with sprinkled stream water to promote germination. Irrigation continues while the seedling's taproot follows the declining water table and can survive without further irrigation. This technique was recently tested experimentally on Boulder Creek near 75th Street (Friedman et. al. 1995). They found a combination of sod removal and irrigation significantly increased the establishment of plains cottonwood from natural seedfall in experimental plots. Establishment of peachleaf willow (*Salix amygdaloides*) was significantly increased only by sod removal. Disadvantages of the disturbance/irrigation method include increased weed control, and the small initial size of seedlings which could lead to high mortality. Also, it would only be feasible to restore small areas at any one time due to the intensive labor needed for twice daily watering for several months during the summer. If only small areas could be restored in any given season, it is questionable whether an entire riparian system could be restored with this method.

Many of the study reaches that support wetland plant communities are unsuitable for this method due to anaerobic soil conditions. However, several sites, including around plots 10a, 11 and 26 would be suitable for establishing cottonwoods and willows. If the disturbance/irrigation method is employed, it is recommended that small areas be restored initially and experimentally controlled to refine techniques for a particular site.

Restoration by planting cottonwoods and willows as cuttings or rooted plants is another option. Cottonwoods have been successfully planted along the South Platte River to restore wildlife habitat, particularly for cavity nesting birds using this method (Snyder and Miller 1992). Establishing cottonwoods and willows from cuttings is accomplished by transplanting cut branches or small trees into pre-augured holes where the end of the stem or trunk can maintain contact with the water table. The cutting subsequently develops adventitious roots and with time a complete root system.

Disadvantages of cuttings include the need to collect and plant propagules, and alteration of the genetic makeup of the community if cuttings cannot be collected locally (Friedman et al. 1995). In addition, creating early successional, young age class stands of trees is impractical with cuttings. However, planting cottonwood and willow cuttings would be an effective way to establish stands of these species if a local source was available. The genetic makeup of the population would be preserved and labor costs could be kept low by minimizing travel time and using volunteers for collection and planting.

Several of the plots on the large terrace where Transect 5 is located would be suitable for planting cuttings including the areas around monitoring wells 3, 6 and 9. Data from these wells show a water table within a meter of the ground surface which would permit auguring of holes and contact with the water table. Monitoring wells could be installed in other likely places to determined their suitability prior to planting.

Another method of establishing cottonwoods and willows is to collect one or two year old rooted individual saplings from naturally occurring stands and transplant them into suitable sites along the stream. Transplants would have the advantage of having a fully developed root system from which to obtain water and nutrients. Watering several times after planting would likely be needed to reduce mortality. This method could be a feasible alternative to, or used in conjunction with, disturbance/irrigation methods and cuttings although it has never been evaluated.

Gravel mines along South Boulder Creek and Boulder Creek are ideal sources for obtaining cuttings and saplings. These mines contain large dense stands of different aged trees that can be collected with minimal impact to the stand. The trees have also regenerated from local seed thereby preserving the genetic integrity of the system.

Fencing select areas along the floodplain to exclude livestock would likely help restore and maintain South Boulder Creek's cottonwood/willow forests. Livestock grazing has been shown to be deleterious to riparian forests in other areas of western North America (Rood and Mahoney 1993, Hanson et al. 1988). Cattle browse and trample seedlings and saplings and may trample and otherwise disturb suitable seed beds. Rotational fencing of small areas would allow trees to reach a sufficient size to survive future contact with cattle. Fences would be later removed. The recruitment of cottonwoods and willows in fenced areas must be compared to unfenced (control) areas to evaluate this method.

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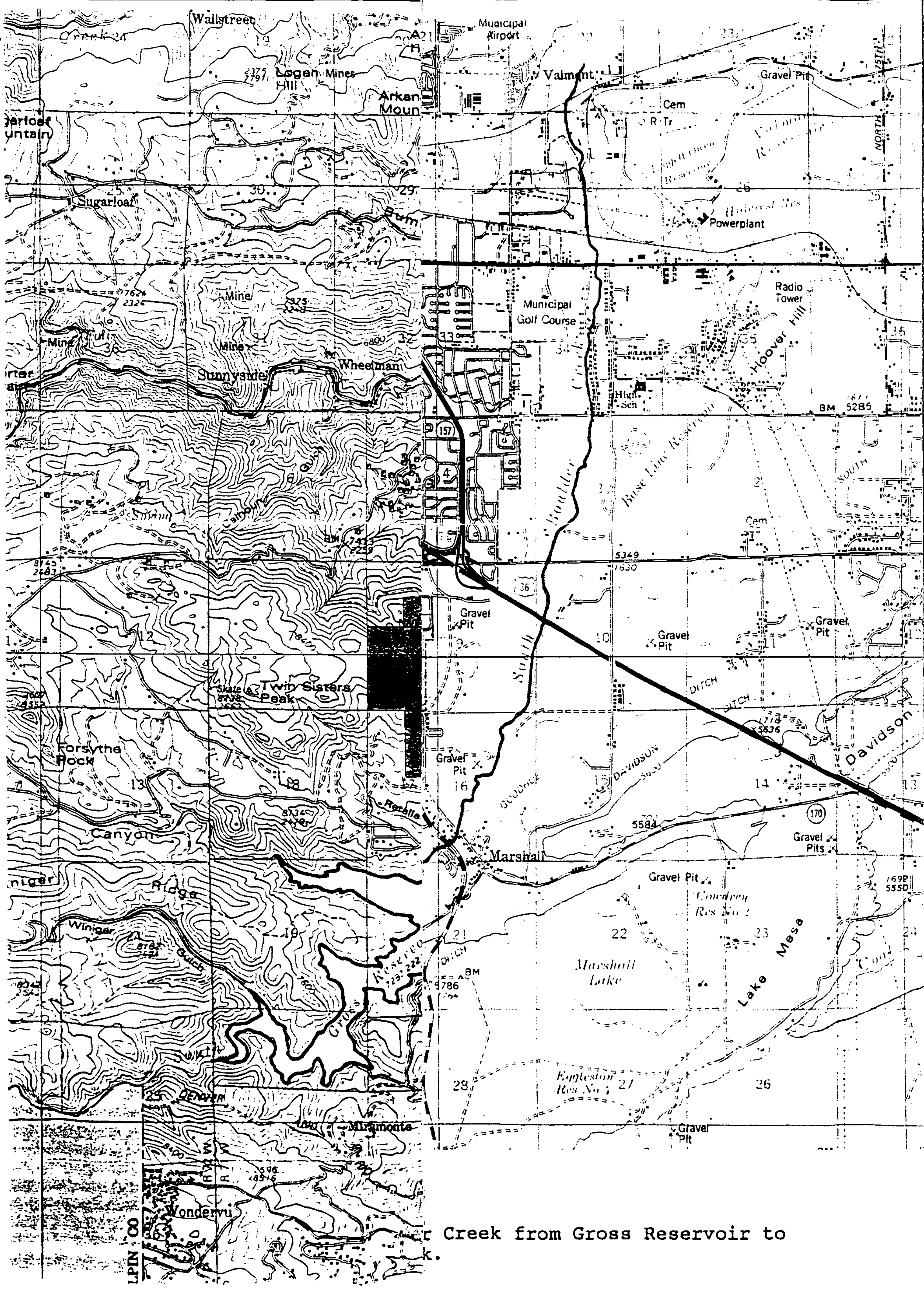

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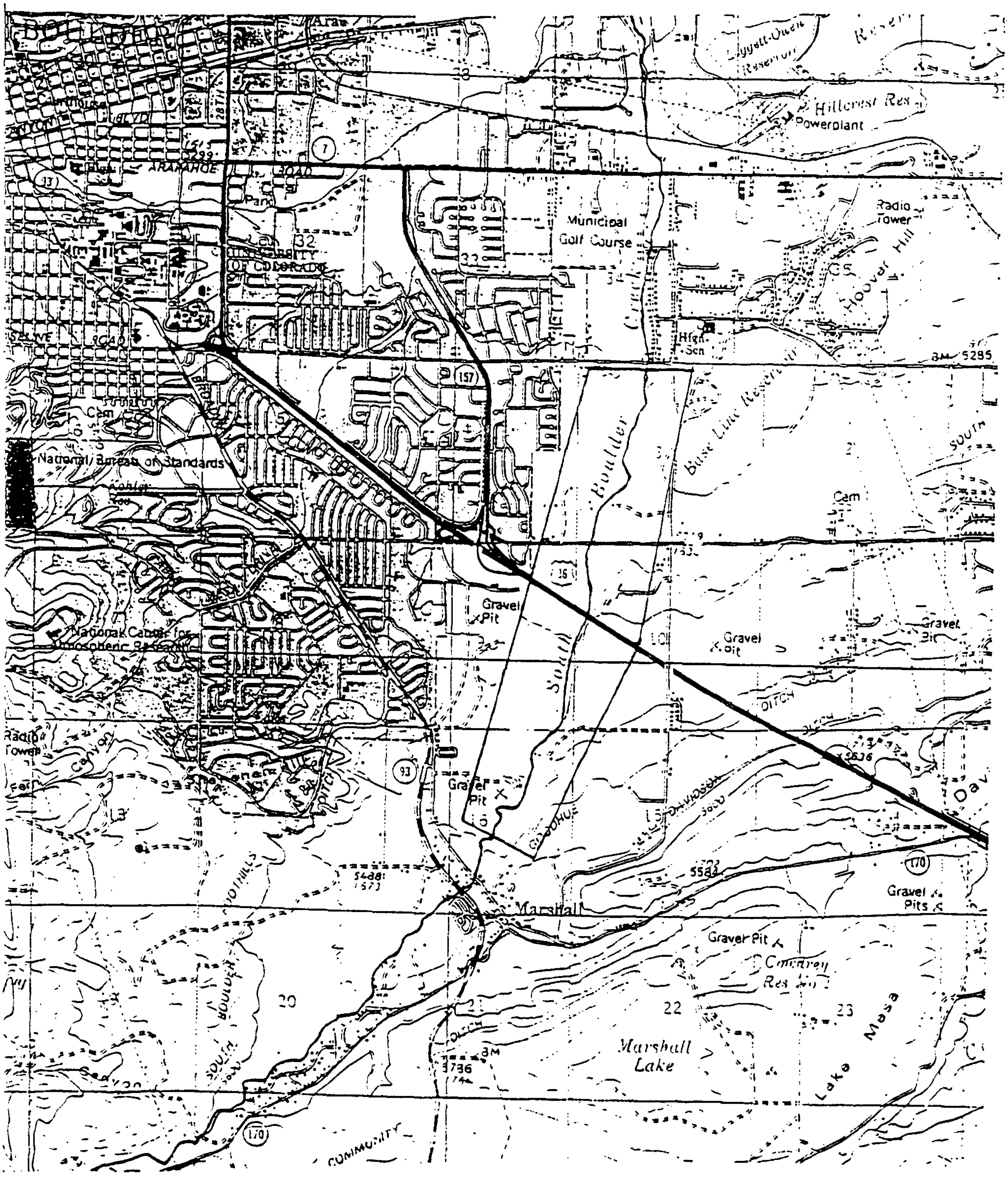


Figure 2. Study area from north of Marshall to Baseline Road.

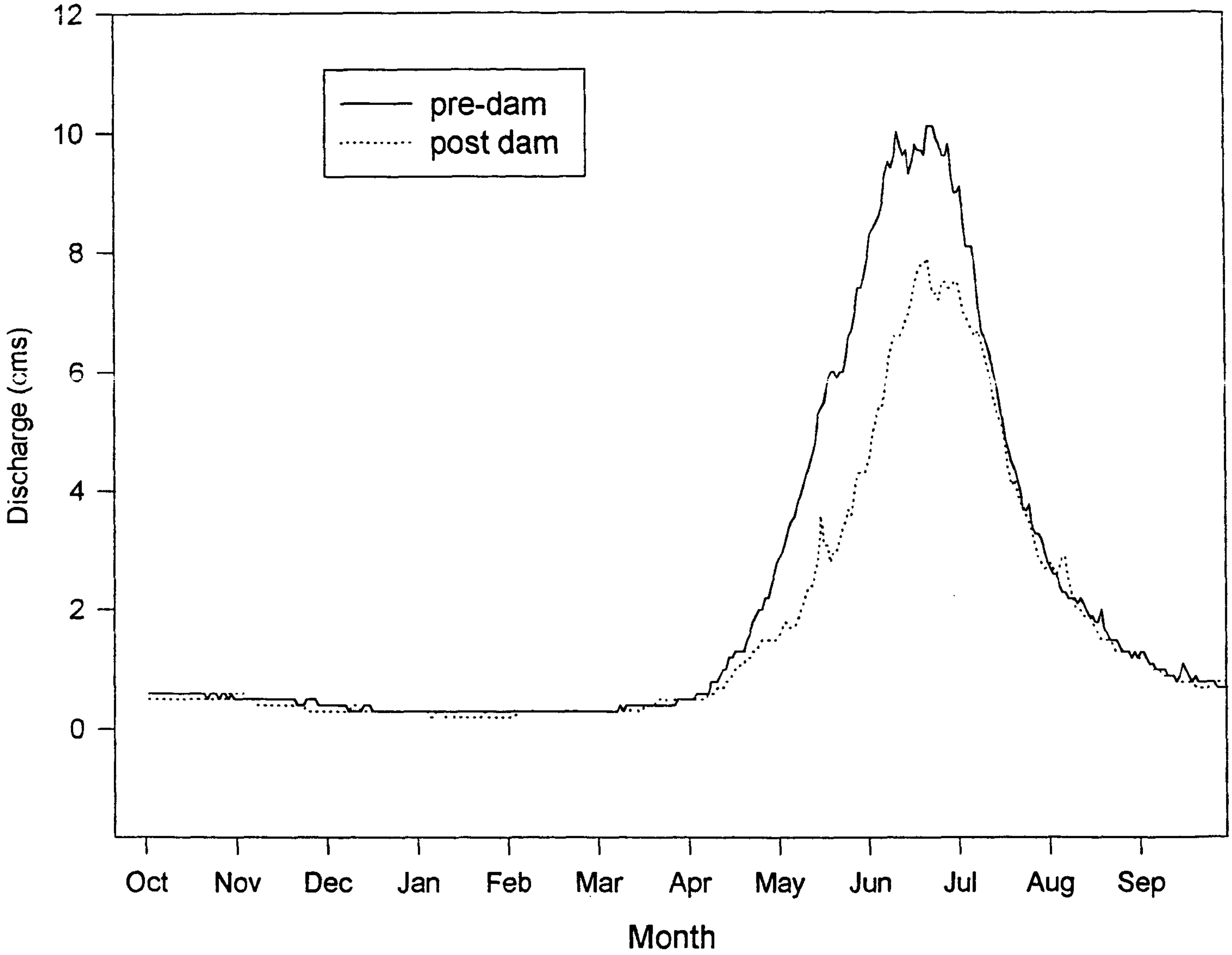


Figure 3. Mean daily flows on South Boulder Creek at Eldorado Springs before and after Gross Reservoir began operation. Pre-dam is 1896-1953, post-dam is 1954-1995.

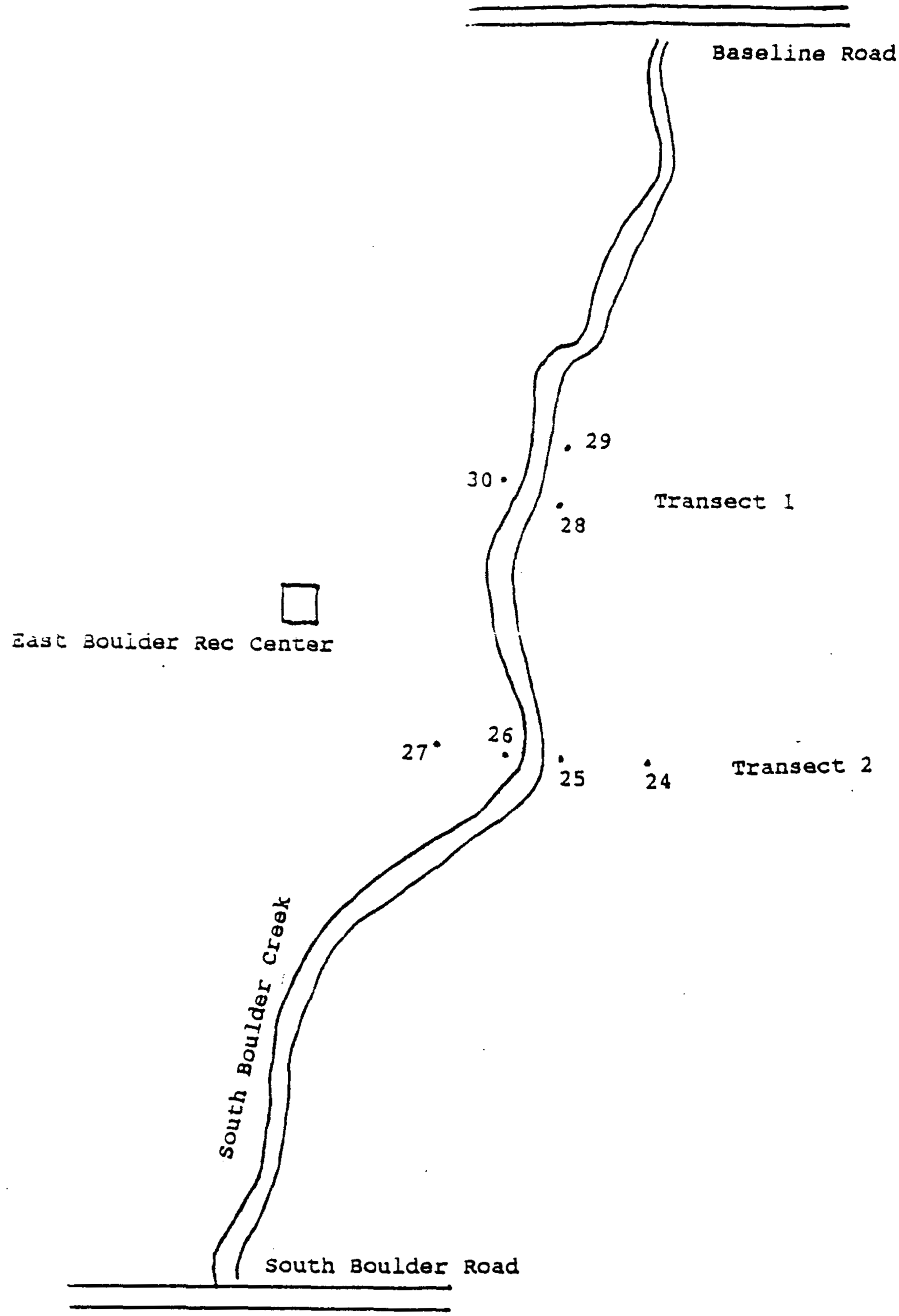


Figure 4A. Locations of monitoring wells and transects.

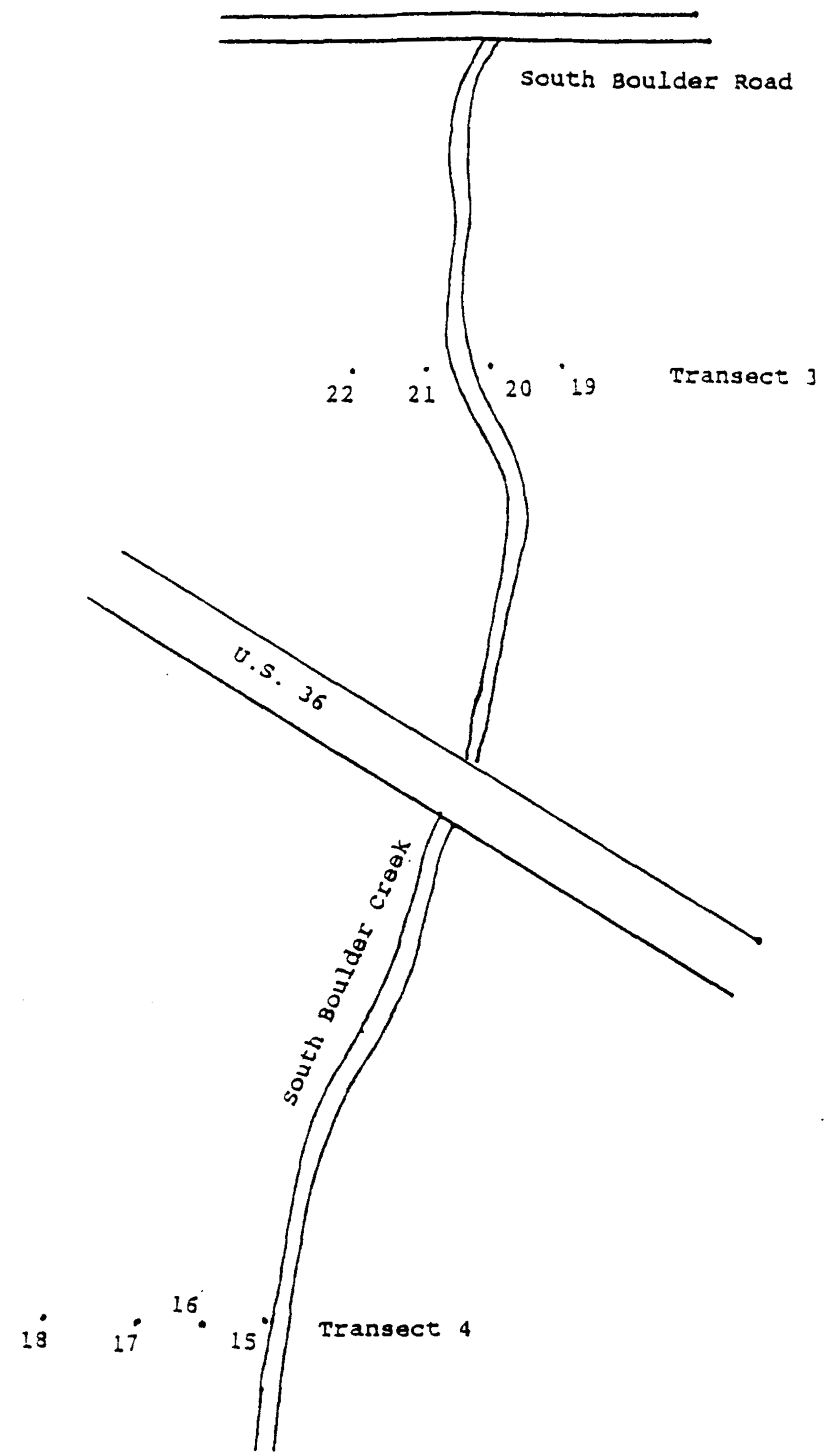


Figure 4B. Locations of monitoring wells and transects.

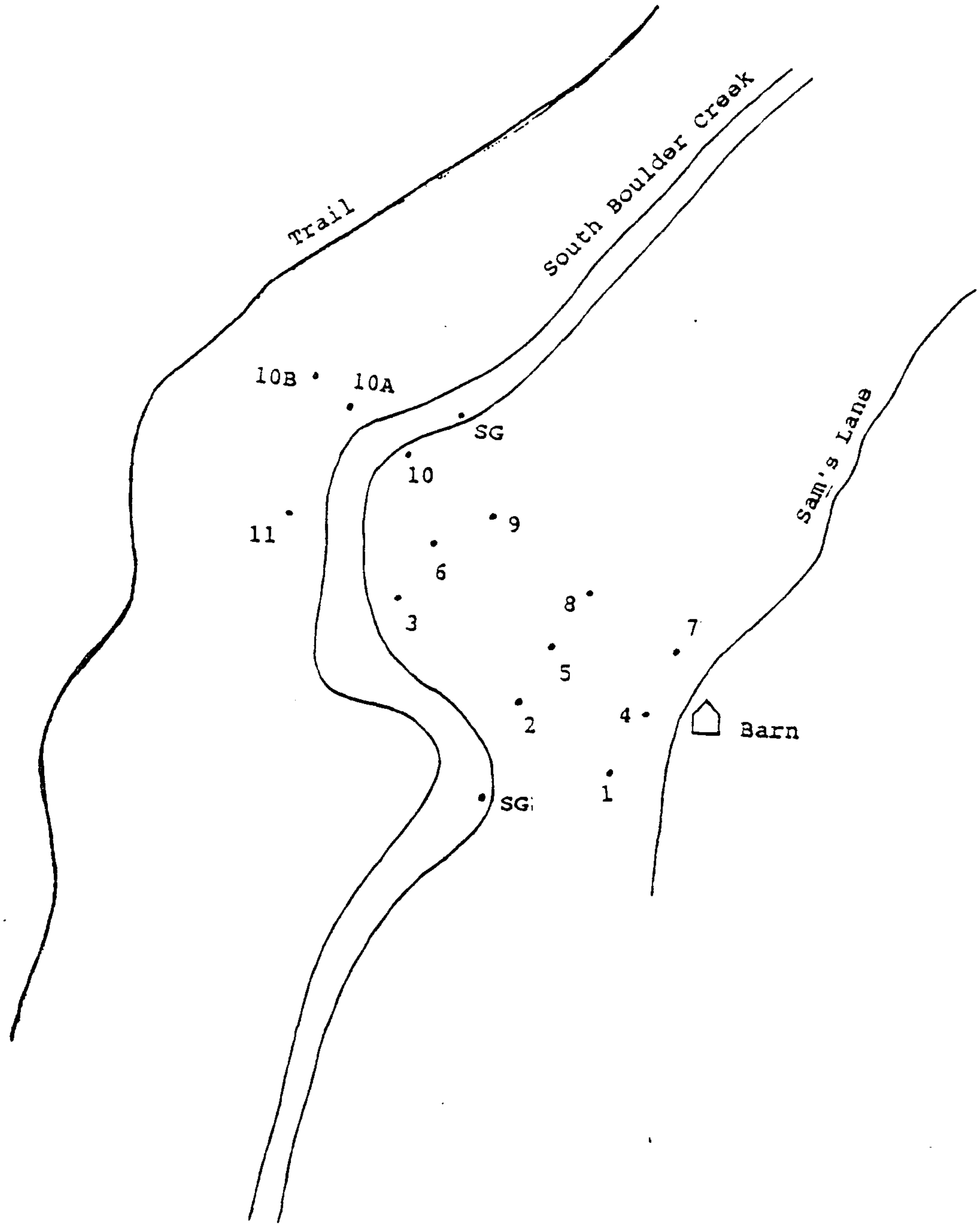


Figure 4C. Locations of monitoring wells and staff gauges (SG). Transect 5 includes wells 7, 8, 9, 10, 10A and 10B.

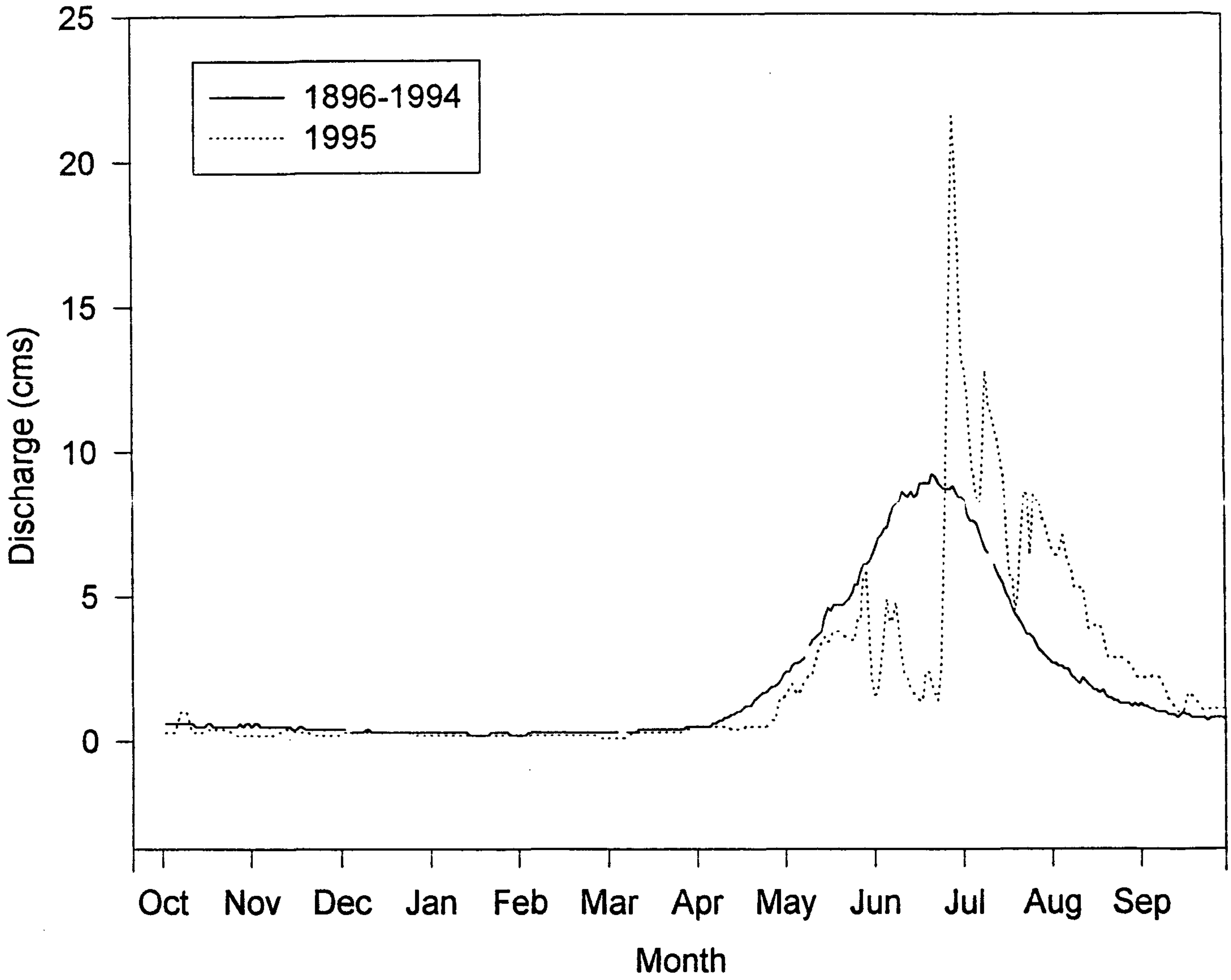


Figure 5. Mean daily flows (cubic meters/second) on South Boulder Creek at Eldorado Springs.

Figure 6. Water table elevations from south to north across south terrace.

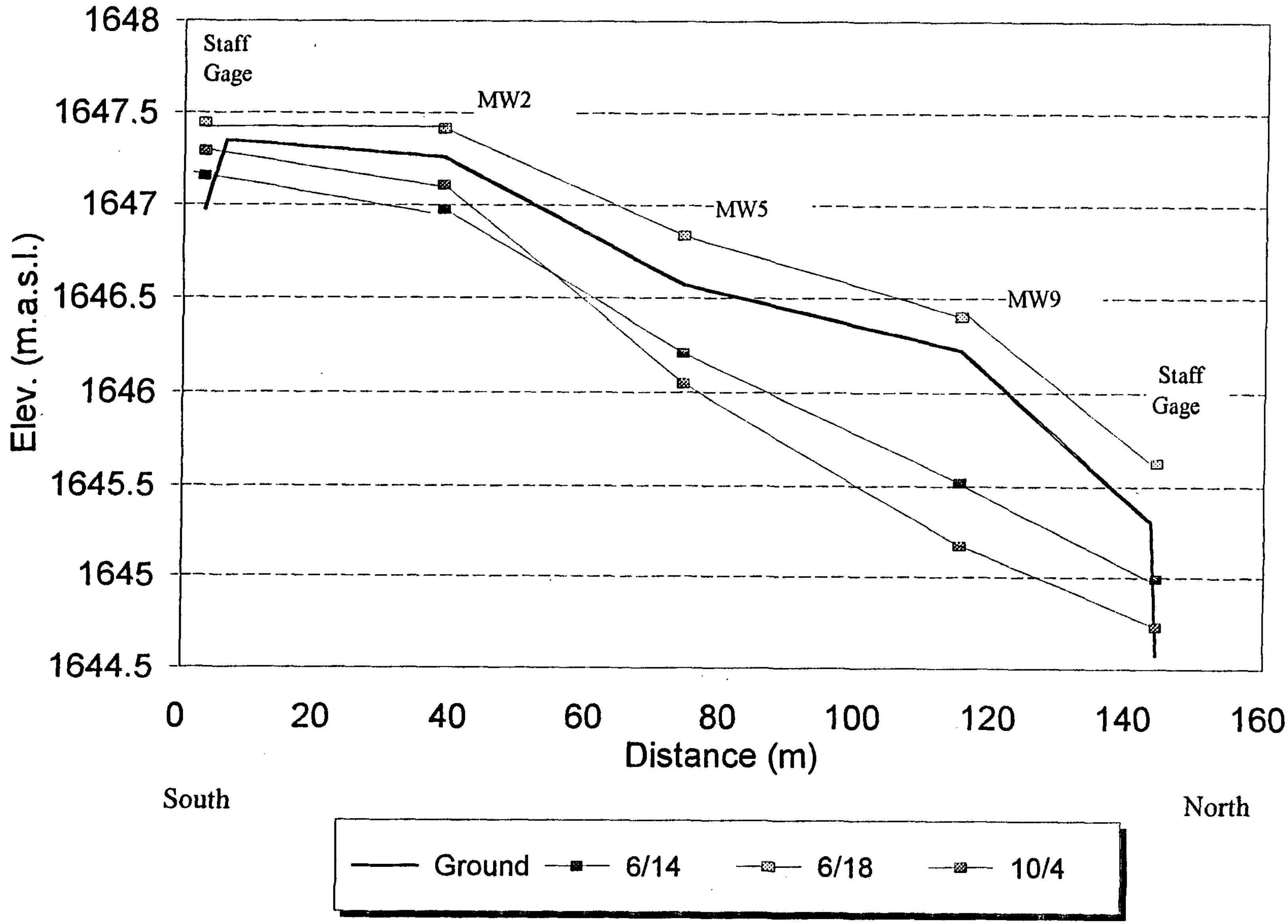


Figure 7. Transect 2.

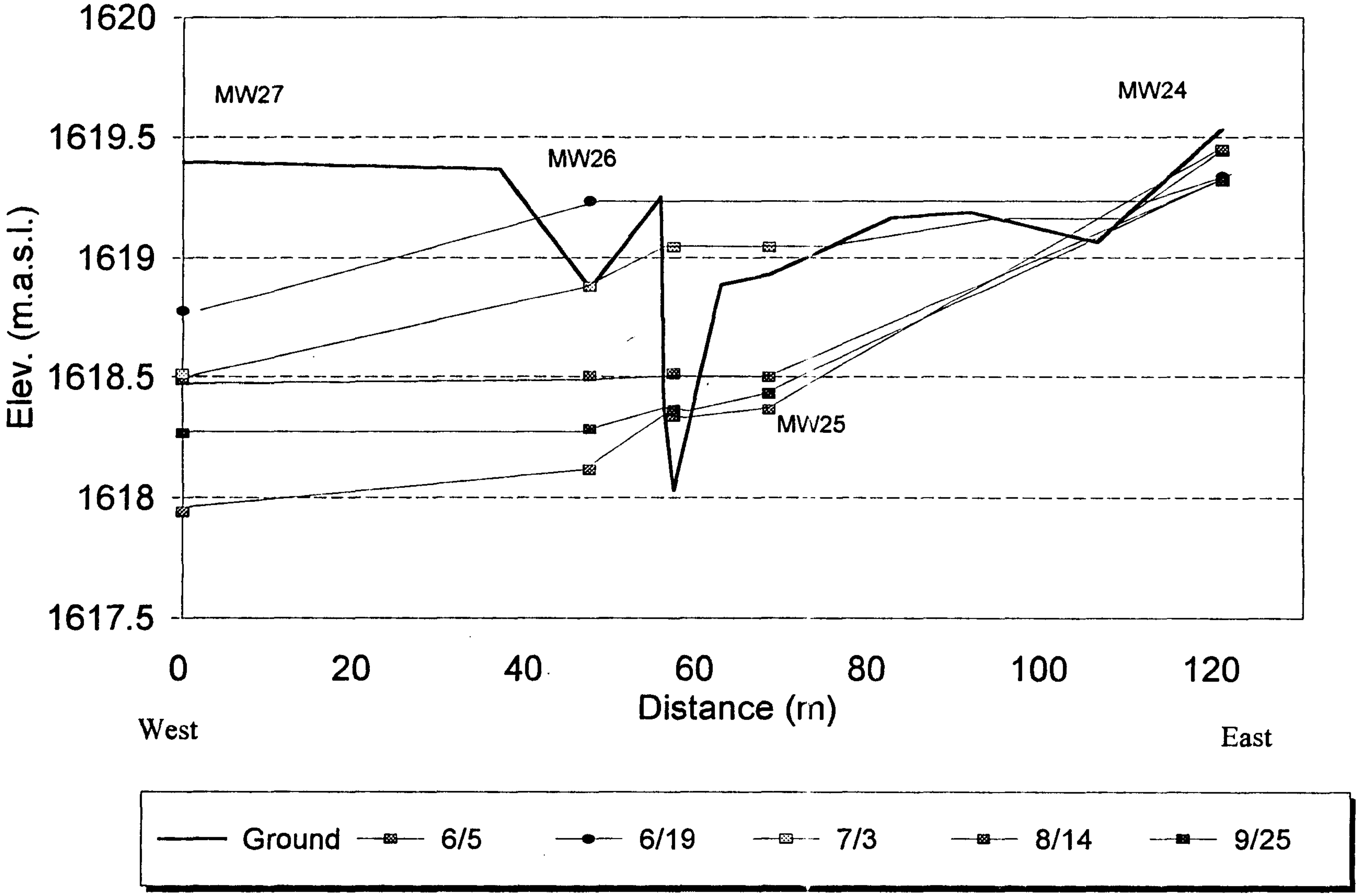


Figure 8. Transect 3.

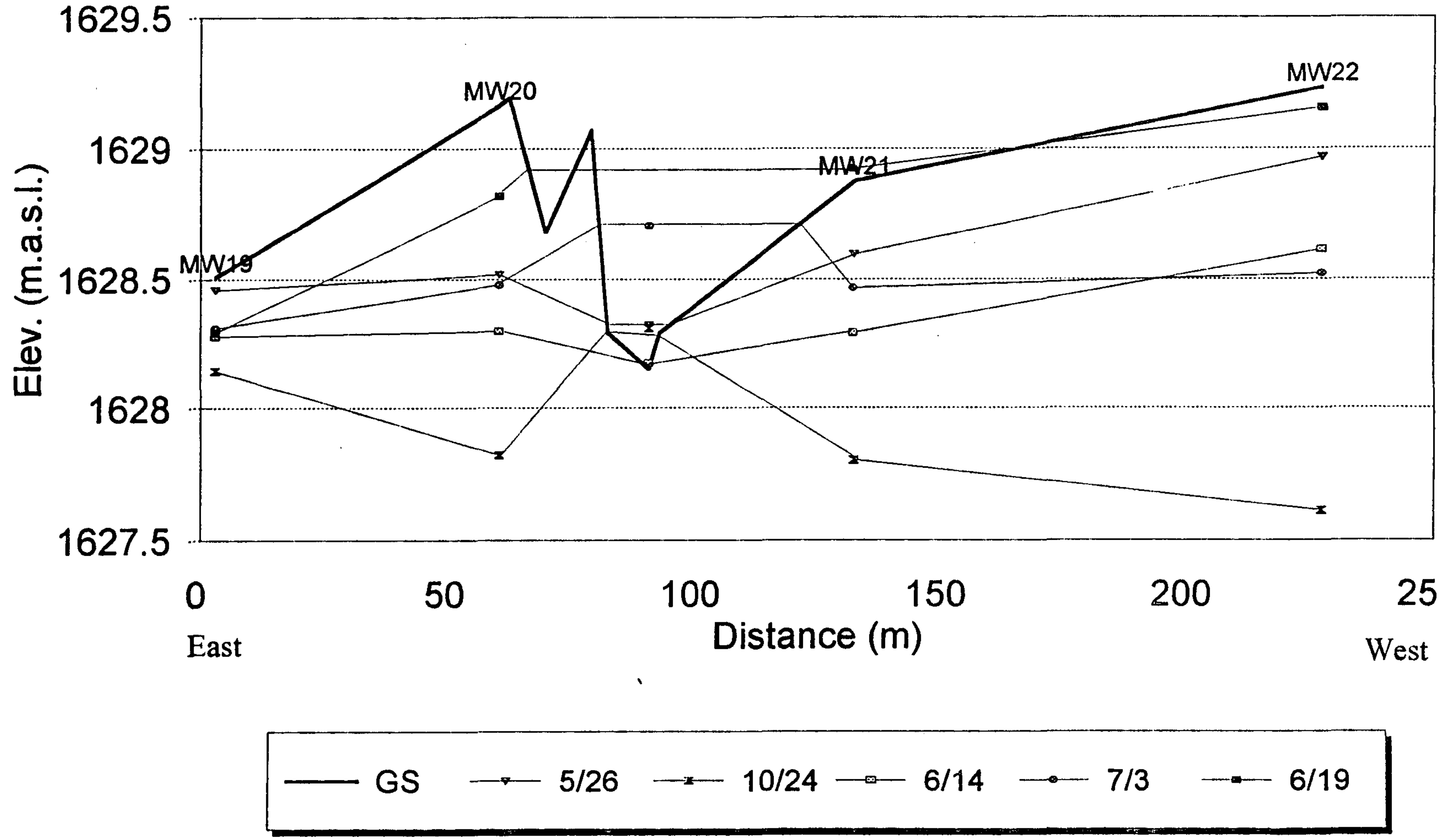


Figure 9. Transect 4.

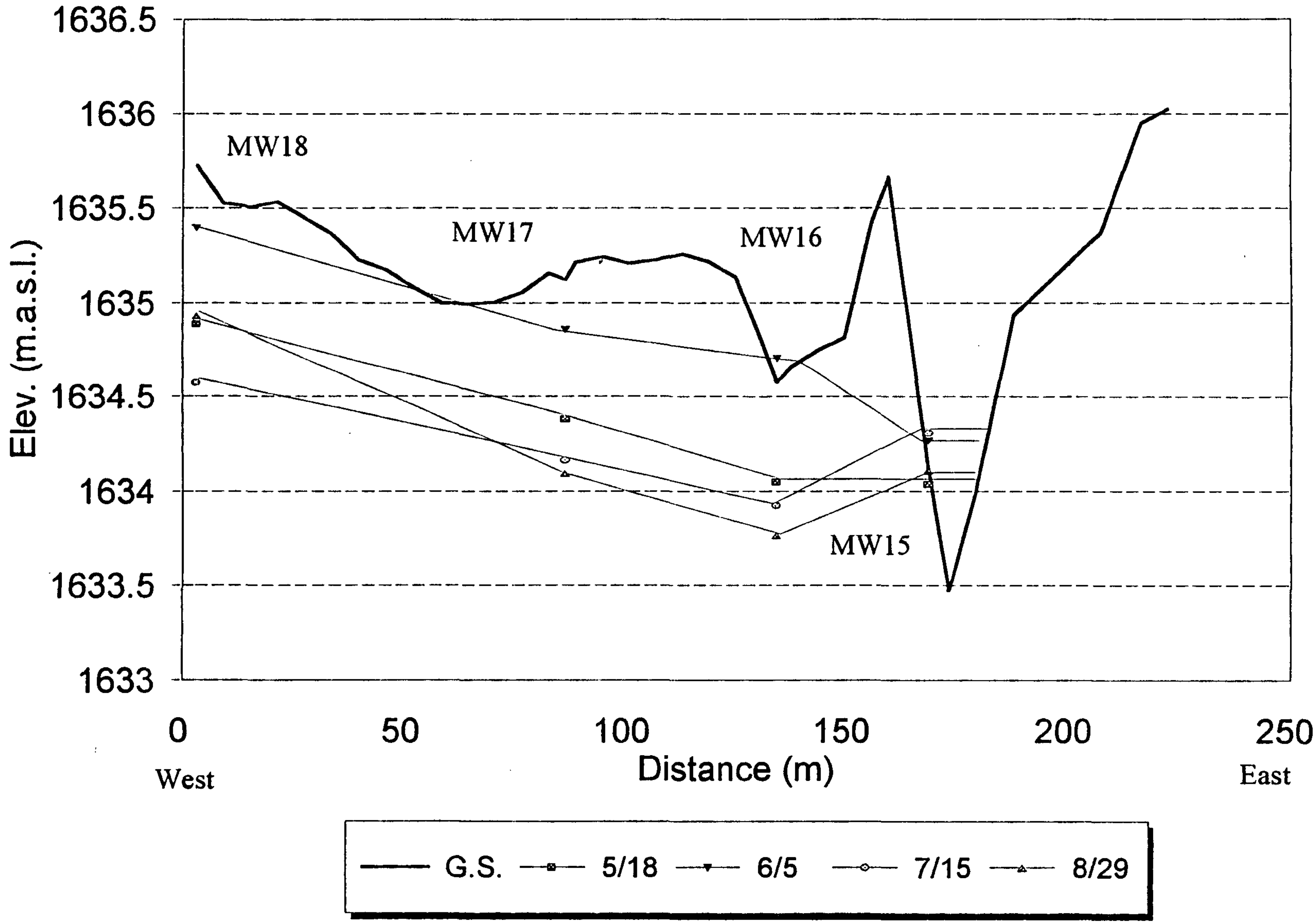
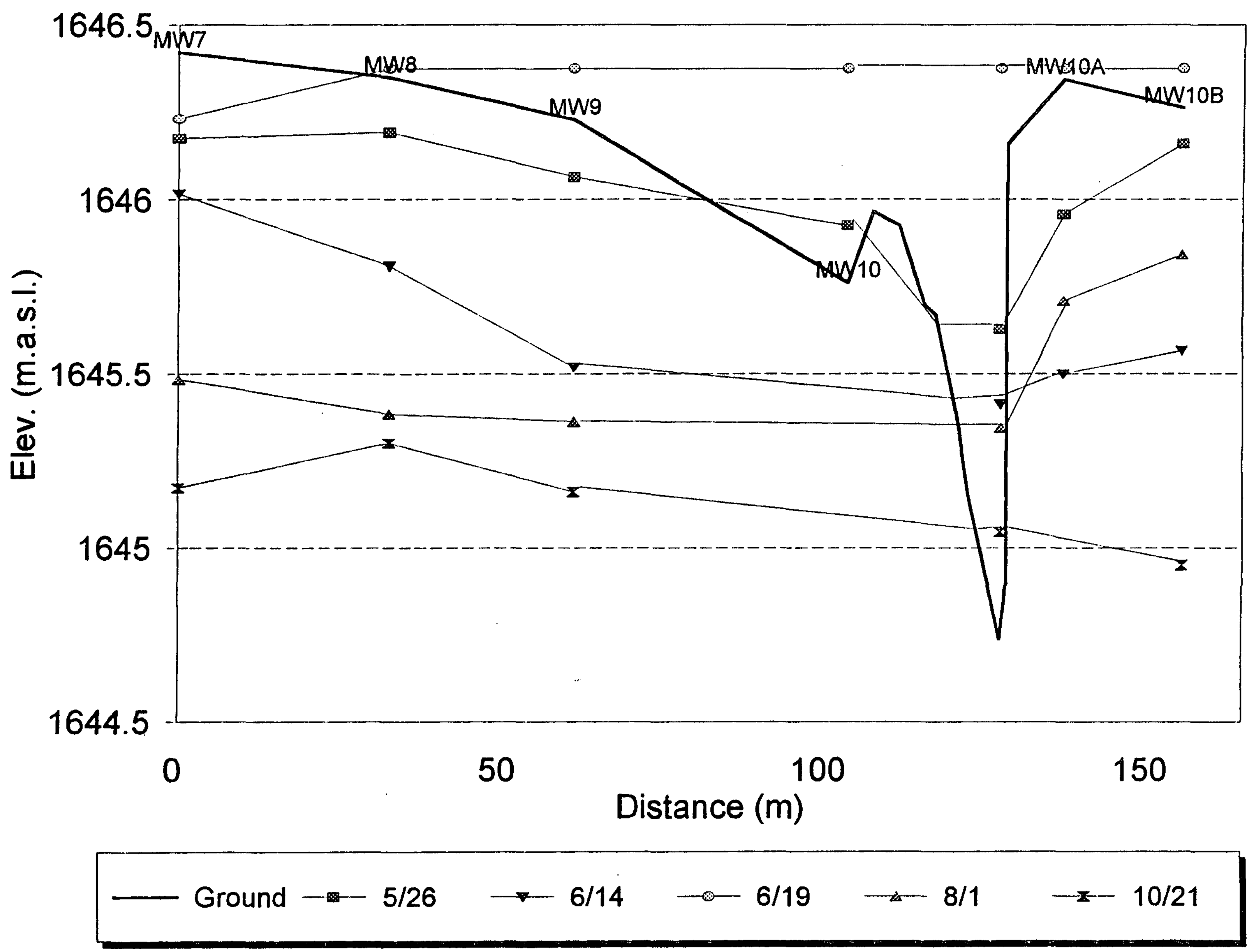


Figure 10. Transect 5.



Well #	pH	cond (μS/cm)	SO4 (mg/L)	Total Hardness (mg/L as CaCO3)	Ca-hardness mg/L as CaCO3	Ca (mg/L)	Na (mg/L)	%Ca to total hardness	Mg (mg/L)	K (mg/L)	Cl (mg/L)
1	7.35	895	180	392.4	259	103.6		66	41.82	1.9	6.8
2	7.42	495	94	195	119	47.6	25.2	61	19.2	1.7	8.1
3	7.4	270					6.42		18.3	7.9	
4	7.4	301	30	111	71.6	28.6	9.95	64.5	10.98	1.5	3
5	7.1	168	0	58.4	35.4	14.2	9.89	60.6	5.91	1.1	8
6	6.97	185					10.1		12.94	2.8	
7	7.48	795	136	378	234	93.6	26.1	61.9	40.5	3.3	33.2
8	7.48	513	43	247	158.6	63.4		64.2			
9	Steel										
10	Dry										
10A	Dry										
10B	Dry										
SG	7.9	84	10	36.4	24.2	9.7	3.94	66.5	2.34	1.1	2.2
11	Steel										
15	8.21	90	12	35.2	23.2	9.3	3.76	65.9	2.54	2.5	2.1
16	7.5	437	44	193.8	120.6	48.2		62.2			8.3
17	Dry										
18	7.2	194	23	76	54.2	21.7		71.3			10.2
19	7.61	211	10	80.6	54	21.6	8.82	67	6.56	1.7	7.2
20	7.45	280	24	79.4	52.8	21.1	10.9	66.5	23.76	10.4	19.6
SG	8.2	100	11	38.6	27.6	11	4.44	71.5	2.88	1	48
21	7.95	470	36	188.6	133.4	53.4	26.6	70.7	16.54	3.5	48
22	Dry										
24	7.67	167	14	62	44.6	17.8	8.42	71.9	4.83	2.4	
SG	7.97	122	16	44.2	32	12.8	6.97	72.4	3.55	1.1	
25	7.44	165	18	40.2	27	10.8	7.52	72.4	7.23	2.5	
26	7.59	220	10	79.4	58.2	23.3	12	73.3	6.25	2.2	
27	7.39	470	52	171.2	118	47.2	31.7	68.9	13.44	3.1	
28	Dry										
29	Dry										
30	Steel										

Appendix 1. Water chemistry data from monitoring wells and South Boulder Creek (SG) collected 26-30 October 1995. pH and EC were measured in the field. "Dry" denotes a dry well at sampling time. "Steel" denotes a steel cased well which could not be sampled. Other missing values were due to laboratory errors.