

BRYCE CANYON WATER RESOURCE STUDY REPORT

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LLYN DOREMUS, Waterworks Consultants

DAVID KREAMER, University Of Nevada At Las Vegas

Llyn Doremus
Waterworks Consultants
10811 36th Ave. SW
Seattle, WA 98146
(206) 244-8640
(206) 244-8636 fax
ladoremus@aol.com email

Dr. David Kreamer
Water Resource Management
University of Nevada, Las Vegas
4505 Maryland Parkway
Las, Vegas, NV 89154-4029
(702) 895-3553
(702) 294-4354 home
kreamerd@nevada.edu email

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ABSTRACT

Discharge measurements collected for this study and for previous investigations indicate a northward migration of groundwater that discharges predominantly to springs on the northeast side of the Park. The actual proportion of discharge from specific springs in relation to the entire discharge quantity from BCNP is difficult to define with the limited data available for springs on the west side of the Park. Within the noted data constraints, the primary discharge from BCNP is in the Water Canyon area, and is interpreted to be supplied by the combined discharge from: infiltration of precipitation in the Water Canyon vicinity; northward trending groundwater movement for the entire length of BCNP; diversion from the Sevier River through the Tropic Ditch to Water Canyon; and interflow of infiltration through Tropic Ditch emitting from the springs in Water Canyon (including Mossy Cave). The water chemistry data suggest different sources for the water in Tropic Ditch and Water Canyon, however, the differences are not substantial and conclusive. The age date of water collected from Mossy Cave suggests an extended subsurface travel time consistent with migration of water infiltrated at the south end of BCNP. Generally, these data suggest that Tropic Ditch infiltration makes up a relatively small, but not insignificant component of the water discharging from Water Canyon in November of 1998.

Water chemistry data reflect the dominant influence of the carbonate lithology of the Claron Formation. The notable differences in sulfate content are attributed to the fact that springs with high sulfate content issue from the Straight Cliffs Formation, and derive sulfate from reaction with the marine sediments of the John Henry Member and the Tibbet Canyon Member of that Formation. The reducing chemical conditions measured in Sheep Creek and Well #1 water samples are likely present also in the Yellow Creek vicinity. Reduction of water with high sulfate content produces hydrogen-sulfide, which is characterized by a distinctive odor. This is the likely genesis of the "stinky" conditions observed at the well drilled by Marine in 1963 and in some of the springs discharging at Yellow Creek.

Bryce Canyon Water Resource Study Report

1 INTRODUCTION

Demand for the water resources of Bryce Canyon National Park (BCNP), is increasing due to increased visitor usage of the Park, and increased water supply needs of the surrounding communities. The Park lands straddle the drainage divide between the Paria River and the East Fork of the Sevier River. The Paria River drains to the Colorado River Basin. Water rights for BCNP under the Federal Reserved Water Rights Doctrine were claimed in the Colorado River Adjudication within Kane, Garfield, Wayne and Piute, Emery, Savier and Sanpete Counties in 1983. To the west, streams originating in the Park drain to the Sevier River, whose waters have been under adjudication since 1936 (Czarnowski, 1991). Water supply for BCNP is drawn from wells in the East Creek drainage and Yovimpa Spring which discharge to the East Fork River and Hopkins Spring.

Water supply for the town of Tropic (located directly east of the Park in the Paria River drainage) is in part supplied by springs that discharge from within the Park. In addition, the Tropic Ditch, constructed in the 1890s, diverts water from the Tropic Reservoir around the northern boundary of the Park. The Ditch drains to Water Canyon, within the Park boundaries, and is captured behind a dam, located within BCNP, at the intersection of Water Canyon and Highway 12. A pipeline, originating at the dam, transports water to Tropic for agricultural and municipal supply. Tropic's water supply has progressively decreased in certainty since the 1980s, due to diminished flows from Bryce Spring and Dr. Goode (Tropic City) Spring, which originate within BCNP and are used for domestic and irrigation supply (Montgomery, 1990). In this environment of restricted water sources, and increasing demand, additional information is required for effective water management. This report provides a conceptual hydrologic model for Bryce Canyon National Park, to aid water resource assessment and management decisions.

1.1 Objectives of This Study

The objective of this study was to better define the conceptual model for water movement within the park using water chemistry and stream and spring flow measurement data. Sample data collected for this study is used with previously collected data to draw a correspondence between the groundwater chemical parameters and the hydrogeologic system supplying water to specific sample locations. A generalized conceptual model for water movement within the Park is constructed from the assembled site specific sample data.

The conceptual model is used to construct a simple water budget using precipitation data collected daily at the Park Headquarters, spring flow measurements, historical water level data and hydrologic parameters, and Tropic Ditch diversion records. These data are interpreted with respect to the specific questions of recharge to the Mossy Cave Springs and the high sulfide content discharge from the Yellow Springs area.

1.2 Bryce Canyon Hydrology Background

Previous studies of the hydrogeology of Bryce Canyon National Park have shown that groundwater flow from the Paunsaugunt Plateau discharges to the east and to the west, migrating along the shallow dipping limbs of the anticline whose axis parallels the length of the Park in a North-South Trend (Bowers, 1990; Marine, 1963; and Gregory, 1951). Marine described groundwater movement in bedrock of the Bryce Canyon area as governed by this general regional geologic structure. The Bryce Canyon anticline, dips downward to the north at an angle of between 1° and 3° , with anticlinal fold "limbs" dipping downward away from the fold axis toward the west and east (Gregory, 1951). Groundwater also migrates northward along the trend of the dipping fold axis (Marine, 1963). Czarnowski (1991) suggests that groundwater movement to the east predominates, as evidenced the by preponderance of springs formed on the eastern margin of the Park along the slopes descending from the Paunsaugunt Plateau. Springs are present also along the western and southern

margin of the Park, likely resulting from lateral movement of groundwater intercepted by the sloped ground surface.

The hydrogeology east of the Park is also impacted by the presence of the Paunsaugut fault. Rock formations along the eastern side of the fault have been uplifted between 1000 and 1500 feet in relation to those on the western side (Gregory, 1951). Consequently, the Tropic Shale on the eastern side, abuts against the higher permeability sediments of the Claron Formation, the Wahweap Formation and the Straight Cliffs Formation on the western side. The rate of water migrating from BCNP toward the east in the higher permeability sediments is significantly reduced when the fault zone is encountered, and moves upward to discharge at the ground surface in the vicinity of the fault zone. Springs likely to result from Paunsaugut fault induced discharge are the Dr. Goode (Tropic City) Spring, Campbell Canyon Spring, Merrill Ranch Spring and Bryce Spring (Marine, 1963).

Shallow subsurface water flow occurs in alluvial sediments deposited in more recent geologic time by the streams and rivers in the Park area (Czarnowski, 1991). Czarnowski suggests that the springs emitting in the East Creek valley are likely to be alluvial in origin. Discharge from springs on the eastern side of the park may also issue, in part, from alluvial sediments.

The hydrogeology of the Park is also influenced in part by the Tropic Ditch. Water diverted to Tropic Ditch is released into Water Canyon on the eastern side of the Park and is recovered and drained into a pipeline near the location where Highway 12 crosses the drainage. Above the pipeline, seepage from the Tropic Ditch is likely to contribute to the flow emitting from springs to the northwest of the Doctor Goode No. 10 spring and the Mossy Cave Springs, according to Montgomery (1990), and may contribute to formation of additional springs and seeps along the length of the ditch. Tropic Ditch also acts as a drainage for other springs and seeps in the watershed (Carnowski, 1991).

2 DATA COLLECTION

Data was collected during the week of November 2 through 6, 1998 from springs and surface water discharging within the Park. Springs chosen for data collection were selected to characterize the chemical properties and physical flow rates representing the range of hydrogeologic conditions. Samples were collected from the East Creek alluvium (Well #1); from the Claron Formation (Mossy Cave Spring and Yovimpa Spring); from the Bryce Point Fault Trace (Peekaboo Spring); from the Straight Cliffs formation (Sheep Creek seep, and Riggs Spring) and from the Tropic Ditch.

Precipitation during the month of October 1998 was higher than any monthly precipitation for October on record, and total annual precipitation for 1998 was the second highest year on record. Consequently, water samples and measurements collected for this project represent high discharge hydrologic and chemical conditions for the Park. Diversion from the Tropic Reservoir to the Tropic Ditch had been terminated shortly before water samples were collected from the ditch. According to Doug Neighbor in a personal communication on November 2, 1998, flow in the ditch had been reduced in the previous week. Flow measured in Water Canyon was supplied by groundwater discharge, and was not augmented by Tropic Ditch flow at the time of measurement.

The locations from which water samples were collected are listed in Table 2.1, and shown in Figure 2.1.

2.1 Data Collection Methods

2.1.1 Spring Discharge Rates

Flow measurements at selected springs were collected using a Pygmy meter or a simple bucket and timing method. Spring sample locations are shown in Figure 1.1 and listed in Table 2.1. Spring and stream flow discharge was measured with a Pygmy meter according to procedures defined in USGS Stream Gaging Procedure

manual (Corbett and others, 1943). Discharge measurements were collected with the Pygmy meter at Yovimpa Spring, Water Canyon and Sheep Creek.

Riggs Spring discharge rate was determined by measuring the time for the spring discharge to fill a calibrated bucket.

Direct discharge rate measurements were not possible at diffuse springs, where water emitted from multiple points in the spring vicinity. These springs include: Whiteman Spring, Peekaboo Spring and Mossy Cave Spring. To estimate the entire flow from the Mossy Cave Spring, flow measurements were taken with a Pygmy meter upstream and downstream of the Mossy Cave Spring confluence with Water Canyon, and subtracted to estimate the flow contribution from Mossy Cave Spring. Discharge from Peekaboo Spring was measured by collecting water from the various discharge points in a calibrated bucket, and recording the length of time to fill the bucket. The individual flow rates were added together to determine the total Peekaboo Spring discharge rate. A flow measurement could not be collected from Whiteman Spring, and the flow rate was estimated visually.

For all measurements collected, the accuracy is likely within 50% of the actual flow rate, due to a variety of factors potentially contributing to measurement errors. Diffuse spring flow measurements are likely to have underestimated the actual flow, due to the fact that seepage from points not detected during measurement were excluded from the measured flow. Pygmy meter measurements were taken in constrained flow systems, smaller than the stream-bed cross sectional area recommended for use with the Pygmy meter. The effect of friction between the water and the stream bed, and between the water and air surface interface, are likely to have decreased the rate of water movement at the measurement point, and consequently yielded a reduced calculated flow rate.

2.1.2 Water Chemistry Analyses

Chemical samples were collected from springs listed and from Tropic Ditch and Well #1. Samples were collected using a clean bucket and funnel to direct water

into four sample bottles. Water samples were collected to ensure that sediment particles were not included in sample containers. Samples were preserved with acid, and samples were not filtered. Immediately after collection sample bottles were sealed, labeled and placed on ice. Samples were shipped overnight express to the analytical laboratory within 48 hours of collection. Samples were analyzed for the cations and anions listed as shown in Table 2.2. The laboratory reports for chemical analyses is included in Appendix A.

Water was collected from Well #1 immediately following removal of 600 gallons from the well bore. The water level was measured at 15" below ground surface before pumping, according to Park water management staff. The well depth is 90 feet below ground surface, and diameter is 12 inches.

Samples for laboratory analysis were collected from a spring discharging from the bank of Sheep Creek. Ferrous iron content was measured for the spring water and for water obtained from Sheep Creek. A flow rate was measured for Sheep Creek, but not determined for the spring from which laboratory samples were collected.

For quality assurance, a duplicate sample was collected from Tropic Ditch and submitted for laboratory analyses. The samples were labeled: Tropic Ditch and Still Spring. Both samples were collected from water ponded in the ditch bottom at identical locations, assumed to be remaining from the flow diverted from the Tropic Reservoir. The results of both analyses are listed in Table 2.3. The analytical laboratory quality assurance test procedures are included in the laboratory reports in Appendix A.

Samples analyzed for tritium content were collected from: Sheep Creek spring, Riggs Spring and Mossy Cave. These two-liter samples were contained in a single glass bottle and shipped to the laboratory for analyses within 2 weeks of collection.

2.1.3 Chemical Parameters.

Chemical parameters were measured during the collection of water sample for laboratory analyses. Parameters measured with an Orion Model 1230 Multiparameter Meter and a Redox sensor kit were: Redox, pH, temperature and dissolved oxygen. During the course of the field data collection, the Orion Meter malfunctioned, and only temperature and redox data were collected from most springs. Ferrous iron concentration was also measured at the time water samples were collected using a Hach colorimetric field kit, with an accuracy of 0.1 milligrams per liter concentration.

2.2 Results

2.2.1 Spring Discharge Rates

Measured spring discharge rates are shown in Table 2.3, with all previously reported flow measurements shown in Table 2.4. Measured discharge rates ranged from 3.2 liters per minute (lpm) at Riggs Spring to 1000 lpm at Mossy Cave Spring, spanning four orders of magnitude. Measurements of discharge from Yovimpa Spring, Riggs Spring and Mossy Cave were also collected by previous investigators. Riggs Spring and Mossy Cave Spring measurements are consistent with previously reported data. However, Yovimpa Spring measurement taken for this study exceeds the previous measurements (Plantz, 1983; and Thiros and Brothers, 1993) by two orders of magnitude.

The surface flow measured at Sheep Creek (122 lpm) was consistent with measurements taken by Ott in 1996 at 67 lpm, and Marine in 1957 at 129 and 182 lpm.

Water Canyon flow was measured at four locations over distance of one half mile, from the most upstream location, below the falls pool, to the most downstream location, the first path crossing of the Water Canyon stream. Measurements locations in downstream order are: one quarter mile upstream of Mossy Cave, just below the falls pool (450 lpm); just prior to the Mossy Cave discharge confluence (1200 lpm); about 100 yards downstream of the confluence (2200 lpm), and about one quarter

mile downstream, at the first path crossing of the creek (3600 lpm). Clearly, this is an influent stream section, and spring discharge along the walls of Water Canyon is visible along the measured stretch of Water Canyon. Plantz estimated discharge from Mossy Cave a 760 lpm in October of 1981, consistent with the 1000 lpm discharge for Mossy Cave calculated from these measurements.

2.2.2 Water Chemistry

Water chemistry data indicates that constituent concentrations are relatively uniform for all samples collected, with some notable exceptions. Chemistry data is presented in Table 2.2. The data are typical of groundwater movement through carbonate lithologies in an arid climate. Calcium and magnesium (calcium ranges from 29 to 110 mg/l and magnesium 21 to 30 mg/l) concentrations are the highest cations. Sodium and potassium, are next highest cation abundances, with concentrations averaging an order of magnitude less (sodium ranges from 2.4 to 10 mg/l and potassium ranges from 0.3 to 9.8 mg/l). Additional metals detected in trace amounts (all less than 1 mg/l) are: aluminum, barium, copper, manganese, titanium, vanadium, and zinc. Titanium was detected, at very low concentrations, only in the Tropic ditch samples. Copper and vanadium were detected in only one and two samples respectively. Barium was detected in every sample (concentrations range from 0.02 to 0.42 mg/l). Iron was also detected in every sample, with ferrous iron present only in water collected from Well #1 (at 1 mg/l), Riggs Spring (1 mg/l), and in Sheep Creek streamflow 0.6 mg/l (ferrous iron was not detected in spring water collected at Sheep Creek for laboratory analysis).

Alkalinity is significantly higher in concentration than any other anions present in samples data collected for this investigation, with the exception of sulfate concentration in the Sheep Creek spring. Sulfate concentration varied more than any other constituent analyzed, ranging from 3.7 to 296 milligrams per liter (mg/l). Chloride concentration ranges from 1.6 to 44.7 mg/l, with the Tropic Ditch concentrations consistently an order of magnitude greater than the other samples analyzed. Fluoride was detected in all samples collected at concentrations of 0.1 to

0.4 mg/l, except for a non-detection at Riggs Spring. Nitrate was detected in all Water Canyon samples (Mossy Cave, Water Canyon, Falls Pool) and at Peekaboo Spring only, at concentrations of 0.2 to 0.4 mg/l.

2.2.3 Tritium Analyses

Age dating of groundwater using tritium content derives from the fact that atmospheric testing of high-yield thermonuclear devices conducted from 1952 through 1964 introduced a spike of tritium to the atmosphere. Subsequent to the bomb-pulse spike, tritium content in the atmosphere gradually decayed, with a half-life of approximately 12.42 years.

Tritium in the atmosphere is incorporated into water that falls to the ground surface as precipitation. Atmospheric tritium concentration is represented in the precipitation that infiltrates to recharge groundwater. Tritium content measured in groundwater is a function of the atmospheric concentration at the time of infiltration, the subsequent decay of tritium in groundwater, and mixing with water more recently infiltrated.

Monitoring of the atmospheric tritium to hydrogen ratio has been conducted by the International Atomic Energy Agency since 1952 (tritium content relates linearly to the tritium to hydrogen ratio, by a factor of 0.31). The atmospheric ratios measured by the IAEA at Flagstaff and Albuquerque are presented in Table 2.5, along with the current tritium ratios calculated for groundwater samples that infiltrated at the corresponding time period. Current tritium ratios were calculated for decay projected to occur subsequent to monitored detections and are compared with the tritium ratios detected in samples, using the method described by Fitzgerald (1996). Tritium content in springs samples collected at BCNP and the corresponding tritium ratios are listed in Table 2.6.

Table 2.6 Tritium Content Detected In Bryce Spring Water

Sample	tritium content (picoCuries/liter)	tritium ratio
Yovimpa Spring	57	17
Sheep Creek spring	6	1.9
Mossy Cave	8	2.5

Comparing the tritium ratios (the tritium ratio is equivalent to a tritium unit) of spring samples collected from BCNP with the ratios shown in Table 2.5, yields a likely date of infiltration for sampled water. The tritium ratio calculated for Yovimpa Spring water suggests an infiltration date approximately 15 to 30 years prior to analysis, suggesting a subsurface travel time of 15 to 30 years.

Tritium ratios for Mossy Cave Spring and Sheep Creek Spring samples are both low. These values are lower than any values calculated for groundwater infiltrated subsequent to initiation of atmospheric testing. The minimum calculated tritium ratio subsequent to testing is 6, as shown in Table 2.5. These data suggest that water from which these springs derived was not exposed to the atmosphere subsequent to tritium pulses associated with atmospheric testing, and therefore infiltrated prior to the initiation of testing in 1952. Water from both these springs likely has a subsurface travel time of 50 years or more.

3 DISCUSSION

Chemical data collected for this study can be compared with chemical data reported by Marine (1963), Plantz (1983) and Ott (1997) for Bryce Canyon National Park springs. Data from this study is compared with Plantz data reported for samples collected in August and October 1981 from Mossy Cave, Merrill Spring, Trough Spring, Tropic Spring and Yovimpa Spring. Marine reports data collected in 1956, 1957 and 1960 from Merrill Spring, Yellow Creek Spring, Sheep Creek Spring,

Swamp Canyon Spring and Well #1. Both studies found similar cation and anion concentrations to those reported here; water chemistry that primarily reflects the carbonate lithology of the Claron Formation. The springs emitting from the Straight Cliffs Formation (Riggs Spring and Sheep Creek Spring) have higher concentrations of sulfate than others sampled, likely resulting from reaction with the sediments deposited in a marine environment that make up two of the four units of the Straight Cliffs Formation.

Spring discharge rates measured for this study, and by previous investigators, vary with the precipitation prior to measurement collection, the local surface topography, the lithology in the discharge location, and the structure of Bryce Canyon region. Variation in measured flow rates for a specific spring or stream is attributed to a rapid hydrologic response to precipitation events preceding the measurement, and the geologic and hydrologic factors discussed in the Conceptual Model Section 5.

The flow rates reported by Plantz and measured for this study are consistently higher than those reported by Ott (1996). These data suggest that different hydrologic conditions differed between 1996, when Ott measured flows, and 1981 when Plantz measurements were collected and the data collected for this study. Rainfall prior to measurements for this study and the Plantz study are indicative of higher than average precipitation months; prior to sample collection in 1981 and 1998 total monthly precipitation exceeded 3 inches for 2 of the 3 months. Conversely, monthly precipitation prior to the Ott sampling was less than 0.4 inches for 3 consecutive months prior to sample collection. Ott's measurement of Yellow Creek discharge is similar in magnitude to the flow measured by Marine in 1960; annual precipitation for both years was below the average annual of 16.39 inches. Provisional precipitation records for Bryce Canyon from 1959 to 1998 included in Appendix B.

3.1 Mossy Cave Spring and Water Canyon

The discharge measured from Mossy Cave Spring and the springs emitting in Water Canyon (combined discharge of 3,600 lpm) is the largest of any measured in the Park during this investigation or by previous investigators. The calculated age of

spring water using the tritium data suggest that water emitting from these springs travels a relatively long distance in the subsurface, over a relatively long travel time.

Measured discharge rates for the Water Canyon vicinity vary between the combined 200 lpm reported by Ott for July 1996 and the combined 3,600 lpm measured for this study. This considerable range of discharge suggest that discharge rates vary in response to recharge from precipitation. The relatively high discharge rate (compared with other spring discharges for BCNP) indicates that the groundwater discharge contribution to Water Canyon flow is of sufficient magnitude to maintain high flow rates, even without the contribution of the Tropic Ditch diversion.

Nitrate was detected in springs samples collected from Water Canyon and Peekaboo spring only, out of all samples analyzed. Plantz also detected nitrate only in Mossy Cave discharge, out of all the samples results reported for BCNP. Consistent nitrate presence suggests oxidizing flow conditions in the Mossy Cave vicinity.

3.2 Tropic Ditch

Water is diverted to Tropic Ditch from the East Fork of the Sevier River, and shows a slight distinction from the water chemistry found in samples collected from within BCNP. Titanium and aluminum are present in trace amounts. Neither of these metals was detected in other samples collected, with the exception of aluminum in Whiteman Spring. Chloride concentration in Tropic Ditch water samples is an order of magnitude greater than any other samples collected. These data, and the presence of nitrate in the Water Canyon samples (absent in the Tropic Ditch samples) indicate that chemistry of water in Tropic Ditch differs slightly from water discharging in Water Canyon. This difference in water chemistry suggests that infiltration from Tropic Ditch contributes a relatively small proportion of the overall discharge quantity from Water Canyon springs.

3.3 Well #1

Water from this well is the primary water source for BCNP. The Well #1 sample is similar chemically to water collected from springs, with the additional detections

trace amounts of copper and zinc. Iron is present in the ferrous oxidation state, indicating reducing conditions in the East Creek well field aquifer (opposite to the oxidizing conditions indicated in the Mossy Cave vicinity).

The average daily well discharge from Well #1 was estimated by Martin (1998) at 112,000 gallons per day or 300 liters per minute, with a maximum summer pumping rate of 120,000 gallons per day. Based on a 24 hour pump test, hydraulic conductivity for the 60 feet thickness of Claron Formation, and 20 feet of alluvium intercepted by the well is calculated at 150 feet per day (3.6×10^{-4} cm/sec).

3.4 Whiteman Spring

Water collected for characterization of Whiteman Spring emits from a diffuse spring approximately 100 yards west of Whiteman Spring, along the ephemeral drainage that both springs discharge to. Both springs eventually drain to East Creek, recharging the aquifer tapped by Well #1. Water chemistry is similar to that of Well #1. However, unlike Well #1, ferrous iron was not detected in this sample. Water ponded below this spring was observed to have a carbon-rich sheen (oil-slick appearance).

3.5 Peekaboo Spring

Flow from Peekaboo springs was measured at 23 lpm, with a temperature of 1.1C. The spring discharges from a steep wall of the Claron formation, and drains to the Bryce Creek drainage. Nitrate was detected in this sample, suggesting oxidizing conditions.

3.6 Sheep Creek

Sheep Creek spring emits from alluvium deposited on the Straight Cliffs Formation. The relatively high sulfate concentration (296 mg/l) suggests a significant proportion of the discharge from Sheep Creek derives from the Straight Cliffs Formation. Marine also reported elevated sulfate concentrations of 364 and 338 mg/l for Sheep Creek. Ferrous iron was detected in water sampled from Sheep Creek, but not from the seep water collected for laboratory analyses.

Flow rates measured by Ott, Marine and those done for this study range from 67 lpm to 182 lpm, suggesting that at least some portion of Sheep Creek discharge derives from a relatively rapid and shallow subsurface water system influenced to some degree by infiltration and discharge from precipitation events. Tritium analyses of seep water indicates that water emitting from these springs may infiltrate over a significant distance in the subsurface, for a relatively long travel of time before discharging. The sulfate content of the seep also implies a longer subsurface travel time, required to allow infiltration to the depth at which reaction with the marine deposited sediments Straight Cliffs Formation may occur.

3.7 Riggs Spring

Flow from Riggs Spring was measured at 3.2 liters per minute (l/m) and 3.5 l/m by Ott. Additionally, the sulfate content was measured at similar concentrations for both samples (40 mg/l and 53 mg/l), suggesting a consistent subsurface supply to the spring that derives in some part from Straight Cliffs formation discharge.

3.8 Yovimpa Spring

Chemistry data collected for Yovimpa Spring is consistent with that collected for other springs emitting from the Claron formation. The likely flow path and hydraulic gradient contributing to the 15 to 30 year travel time calculated for Yovimpa Spring flow is discussed in the Conceptual Model Section (5).

Yovimpa Spring discharge is collected in a storage tank for supply to the visitor station located at Rainbow Point. Overflow from the tank discharges to the Creek bed, where measurements were collected for this study. The order of magnitude difference between the discharge rate reported by Plantz (1983) and Thiros and Brothers (1993), both 4 lpm, and the value reported here is likely due to impacts of the storage tank on the discharge rate or the measurement technique.

4 HYDROLOGIC BUDGET

A very generalized hydrologic budget is proposed here, to facilitate comparison of the quantity of water discharging from springs with the overall quantity of water that annually discharges from BCNP. The budget is presented only for discussion and conceptualization purposes. It is not intended as a quantitative tool from which water management decisions can be derived. A numerical computer model of the Bryce Canyon area is required for quantitative interpretation of flow within the park. Numerical modeling was beyond the scope of work for this study.

4.1 Hydrologic Budget Equation

A simple hydrologic budget balances the amount of water that enters the hydrologic basin annually with the amount flowing out of the basin and the amount stored in the basin. Water enters as precipitation, and leaves as evaporation, transpiration, surface flow and groundwater flow. Freeze and Cherry (1979) show this in equation form as:

$$P = Q + E + \partial S_s + \partial S_g$$

where: P = annual precipitation

Q = total annual spring and stream discharge

E = total annual evaporation and transpiration

∂S_s = change in surface water storage

∂S_g = change in groundwater storage.

This budget is simplified further because the data with which to estimate surface water storage and groundwater storage was not available at the time of this study. These components are assumed to average to zero over a long enough time frame (Freeze and Cherry, 1979), and that assumption is incorporated into this budget. The high evaporation rate present at BCNP, and the lack of surface standing surface water bodies support the assumption that surface water storage is not occurring. Groundwater storage is likely, however, although not well enough

quantified at the time of this study to be incorporated into the budget. Groundwater storage is discussed further in the Conceptual Model Section (5). Another way that the assumption of zero annual change in groundwater storage can be considered is to equate the uncertainty in the recharge quantity estimate with the uncertainty in the change to groundwater storage annually.

One combined value for evaporation and transpiration (evapotranspiration) is used for the purposes of this estimate, because estimation of either evaporation or transpiration value requires collection of extensive biologic, precipitation and atmospheric data not available for this study.

Recharge to the park is augmented by flow in the Tropic Ditch, discussed in Section 4.3. Removing the groundwater and surface water storage factors and adding the Tropic Ditch contribution to recharge modifies the hydrologic budget equation to:

$$P + Q_{TD} = Q + E$$

Q_{TD} is equal to the amount infiltrated through Tropic Ditch that discharges to Water Canyon. Implicit in this budget is the assumption that additional infiltration of Tropic Ditch water further downstream in Water Canyon does not occur; Tropic Ditch is assumed to flow completely through Water Canyon, discharging at the eastern Park boundary. This equation will be used for the purposes of this hydrologic budget estimate.

4.1.1 Recharge From Infiltration

For this estimate, the entire area of BCNP is assumed to be a recharge zone. That is, all precipitation that recharges groundwater in BCNP is assumed to infiltrate before discharging to springs, streams, and from pumping wells. The recharge rate is assumed to be constant throughout the year. Because it is assumed that there is no groundwater storage, all infiltrating water then discharges in the same year. All discharge rates are also assumed for purposes of this budget estimate to be constant throughout the year.

Recharge to the valley-fill aquifer by infiltration of direct precipitation was estimated to be 5 percent of the average annual precipitation for the Sevier River basin by Thiros and Brothers (1993). The proximity of the Sevier River to BCNP suggests the climatic conditions used to derive the Sevier River recharge estimate likely contribute to a similar recharge rate at BCNP. For this estimate, it is assumed that the portion of precipitation that doesn't infiltrate and recharge groundwater is evapotranspired directly to the atmosphere from ground surface, surface water runoff is not accounted for in this budget. Estimates using recharge rates of 5 percent and 10 percent of annual precipitation are used to calculate recharge to groundwater to allow consideration of the potential variability in the climatic conditions influencing recharge rates. Recharge calculations are shown in Table 4.1.

4.1.2 Tropic Ditch Infiltration

Tropic Ditch diverts water from the East Fork of the Sevier River to the City of Tropic in the Paria River basin through a canal approximately 12 miles in length. The average annual quantity of water diverted for the years of record is 4,748 acre feet, with a maximum recorded annual diversion of 7,022 and a minimum of 2,474 acre feet. Tropic Ditch diversion records are included as Appendix D. The amount of water that is actually received in the Paria basin is estimated by Thiros and Brothers (1993) at 2,610 acre feet per year (55 percent of the diverted quantity) based on work by Carpenter et al. (1967). This estimate indicates a combined infiltration and evaporation rate of 45 percent from the Tropic Ditch.

Infiltration losses estimated from canals in the Sevier River basin based on the sediment size and genesis of canal beds ranges from 10 to 40 percent of the diverted quantity, according to Thiros and Brothers. Canals constructed in permeable deposits, as Tropic Ditch canal is, may reach the larger estimated infiltration rate of 40 percent, similar in magnitude to the Carpenter estimate. An estimate of the potential infiltration losses from the Tropic Ditch, prior to its entrance to Water Canyon, is shown in Table 4.2. These estimates use the assumption that only water infiltrating in the last 2 to 3 miles of Tropic Ditch discharges to Water Canyon, which represents

approximately 20% of the length of the canal. The remainder of the infiltration through the Tropic Ditch is assumed to drain to drainages topographically isolated from Water Canyon, along the ditch length from Tropic Reservoir to Syrett Hollow. The calculated contribution of water infiltrating from the Tropic Ditch that discharges to Water Canyon ranges from an annual average of 0.07 cfs (116 lpm) to 0.70 cfs (1,190 lpm). If the values for annual infiltration are considered in light of the fact that water is diverted to Tropic Ditch only from April to October (for one half the year), the actual infiltration rates are probably twice those calculated. The volume calculated to infiltrate annually remains the same however.

4.1.3 Evapotranspiration Estimate

Simplifying assumptions are used to derive a value for evapotranspiration, due to lack of data. Evapotranspiration is assumed to be 95 percent of measured precipitation, based on Thiros and Brothers estimates of infiltration rates in the Sevier River Valley (evapotranspiration is assumed to consume the entire water volume precipitated that doesn't recharge groundwater). Additional data with which to refine this estimate was not collected over the course of this study.

4.1.4 Discharge Estimates

To estimate total discharge from the Park, three components are combined: 1) measured and estimated spring discharge within BCNP (for the west and east sides of the Park), 2) pumping from the alluvial aquifer of East Creek as calculated by Martin (1998), 3) discharge of springs along Paunsaugunt Fault. The estimates and referenced measurements are shown in Table 4.1 and Table 2.4 respectively. For springs with multiple discharge measurements an average value was selected to represent the annual discharge rate. The average values are shown in Table 4.1.

4.2 Water Budget for Bryce Canyon National Park

4.2.1 Estimated Recharge

Estimated groundwater recharge from infiltration of precipitation and infiltration from Tropic Ditch ranges from 2,400 to 7,400 acre feet per year. The smaller value

represents a 10 percent infiltration rate from Tropic Ditch added to a 5 percent infiltration of annual precipitation onto the entire area of BCNP. To obtain the larger value, infiltration through Tropic Ditch is using a 40 percent rate is added to 10 percent of 1998 annual precipitation. The recharge estimates span a three fold difference in infiltration quantities. Actual precipitation recorded at BCNP differs by two fold; the range of three-fold estimated infiltration is similar to the two-fold range in precipitation variability, suggesting that the estimated quantities generally reflect actual conditions.

Precipitation recorded for 1998 was the second highest for the 39 year period of record. In 1998 precipitation of 23.42 inches was recorded; the maximum recorded is 25.06 inches, and the average over 34 years is 16.39 inches. Consequently, the spring discharge measurements collected in November 1998, similar to the precipitation measurements, likely represent an extreme high.

The quantity estimated for annual BCNP discharge (3640 acre feet) falls between the minimum (2,440 acre feet) and maximum (7,360 acre feet) quantities estimated for recharge. The discharge estimate is based in large part on 1998 measured flows, which likely represent the highest potential discharge rates. To evaluate the hydrologic budget calculated, the discharge estimate is better compared to the maximum estimate for recharge.

4.2.2 Relationship between Recharge and Discharge

Comparing the maximum estimated recharge (7,359 acre feet) with the discharge estimate (3,637 acre feet) reveals that almost half of the quantity estimated to be recharged is not accounted for in discharge. The discrepancy may be due to the lack of information for discharge from the west side of BCNP. Czarnowski (1991) noted that the majority of the discharge flows from the east side of BCNP. This interpretation is supported by the fact that the area supplying water to the east side springs is larger than the area supporting discharge from the west side of the park. However, the nine-to-one east-to-west proportion of flow used for the discharge estimate likely underestimates the actual discharge from the western side of the Park. For the East Creek drainage, discharge is represented entirely by pumping data from

Well # 1. Discharge measured from only one spring (# C37-4-31CBB) accounts for flow from all the remaining west side drainages. Flow data from the following west side drainages was not available in calculating this hydrologic budget: Podunk Creek, Oak Hollow, Long Hollow, Ingram Hollow and seven unnamed drainages (including one containing the unnamed spring used).

The difference between the discharge estimate and the recharge estimate may not be entirely accounted for by discharge from west side drainages. Some portion of the difference is likely due to deeper infiltration of water recharged in BCNP, held in storage in the aquifer and discharging to the Sevier River and Paria River considerably downstream from the Park boundaries.

Another explanation for the differences in estimated recharge and discharge quantities is that discharge may remain relatively constant compared to the range in recharge. Groundwater storage may account for the differences in calculated annual recharge and discharge. Although 1998 was a high precipitation year, previously collected data suggests that the flows measured in 1998 are close to average conditions. Plantz estimated Mossy Cave discharge at 760 lpm in 1981. The 1981 annual precipitation of 17.75 inches is close to the 16.39 thirty year average, suggesting that the 1000 lpm measured in 1998 may be representative of average precipitation year conditions. Marine (1963) reported similar discharges rates for Sheep Creek in 1957 (182 lpm and 129 lpm, in May and September of that year) to the 1998 measurement. These values bracket the 122 lpm measured in 1998, suggesting also that the 1998 discharge may not vary significantly from discharge conditions of average precipitation years.

4.3 Tropic Ditch Contribution to Discharge from Water Canyon Springs

Compared with the total annual discharge estimate, the discharge from Water Canyon (1998 measurement) constitutes almost half of the annual discharge from the BCNP. What is the likely source for the disproportionately large flow through Water Canyon? It is unlikely that half the recharge area of BCNP discharges to Water Canyon. The maximum estimated infiltration through Tropic Ditch (shown in Table 4.1)

to Water Canyon and the surrounding area springs is 0.7 cfs (17,000 lpm). This quantity is half of the flow measured in Water Canyon. During the dry summer months, when water is diverted through Tropic Ditch, it's likely that infiltration from Tropic Ditch may contribute up to half of the discharge from Water Canyon. However, a more accurate estimate of the Tropic Ditch contribution to Water Canyon and Mossy Cave flows will require additional data and analysis.

5 CONCEPTUAL MODEL OF HYDROLOGIC SYSTEM

5.1 Lithologic Influence on Infiltration

Evidence of lithologic influence on infiltration can be found in the chemistry of springs water samples. Shallow infiltrating water migrates significant distances in the Claron Formation, based on the tritium data interpretation for Mossy Cave. Springs infiltrating only to the depth of the Claron formation display the dominant carbonate chemistry associated with the limestone deposits that make up the Claron Formation. Higher sulfate concentrations in BCNP springs suggests deeper infiltration depths. The maximum Claron Formation thickness is approximately 800 feet (Bowers, 1990). Underlying the Claron Formation, and separated in some locations by the Wahweap formation (maximum thickness 400 feet) is the Straight Cliffs Formation. The upper part of the Straight Cliffs Formation, with a thickness of about 1,000 feet, was in part deposited under marine conditions, with inclusions of sulfurous coal (Bowers, 1990; and DeCourten, 1994). Groundwater with higher sulfate concentrations is likely to have infiltrated over 1,000 feet, through the Straight Cliffs Formation, prior to discharging. Long flow paths in both the lateral and vertical direction are indicated by the tritium data, through both the Claron Formation and Straight Cliffs Formation.

5.2 Structural Controls on Groundwater Movement

As Marine observed, the spectacular lithologies and the geologic structure of BCNP determine in large part the movement of water in the subsurface. The Bryce Canyon Anticline, with axis dipping downward to the north, continues its northward

dipping trend in the next syncline to the north. The syncline axis intersects Water Canyon, possibly acting as a subsurface funnel that drains into Water Canyon. The extended northward plunge of the anticline and syncline axes, along most of the length of the park, apparently directs groundwater migration for the entire length of the Park toward the north. Discharge from Water Canyon and Yellow Creek drainages, along the northeast margin of the Park, are the largest flows measured for drainages originating in the Park boundaries, and together discharge the majority of water that flows out of the Park.

The preponderance of flow to the north is also reflected in the relatively small discharge quantities from the springs at the southern end of the Park. Flows measured from south springs were less than 10 lpm for: Iron Spring, Natural Bridge Spring, Riggs Spring, Ponderosa Canyon Springs, Bulberry Spring, Black Birch Canyon Springs, and Agua Canyon Springs (Ott, 1996). Only Yovimpa Spring has been measured at flows greater than 10 lpm (this study, 120 lpm in 1998). Czarnowski made a similar comparison between spring discharges from the north and south ends of BCNP.

The tritium ratio measured for Yovimpa Spring indicates that water discharging at Yovimpa infiltrated approximately 15 to 30 years ago. The shorter travel time for Yovimpa Spring discharge than other springs measured, together with the relatively minor discharges from springs at the south end of the Park suggests that the majority of infiltration at the south end of the Park does not discharge in that vicinity. A small portion of water infiltrated in the south end travels through the relatively shorter path length to discharge at springs in the southern Park vicinity. Most water infiltrating at the southern reaches of the park migrates along the northerly structural dip and discharges from the more distant park springs to the north.

5.3 Paunsaugunt Fault-Related Groundwater Movement

Fault induced springs have formed along the northern extent of the Paunsaugunt Fault, along the northeastern margin of BCNP. The proposed mechanism for fault influence of spring discharge is illustrated in Figure 5.1, derived

from Marine (1963). The springs are associated with the Paunsaugunt Fault, which parallels the north-south trend of the Bryce Anticline at a distance of one to four miles east of the anticline axis. Springs generated by flow along the Paunsaugunt Fault are described by Marine: Merrill Ranch Spring, Bryce Spring, Campbell Creek Spring and Dr. Goode (Tropic City) Spring; all located north-northeast of Yellow Creek. The fact that the observed springs are located at the northern extent of the fault trace suggests that the northward dipping fold axis and corresponding groundwater flow supports discharge from fault related springs as well as springs discharging at higher elevations within the Park. According to this interpretation, the source water for the fault-associated springs potentially derives from the same source that supplies Water Canyon and Yellow Creek. However, data with which to better evaluate this hypothesis was not collected for this study.

If groundwater migration to the north along the axis of the dipping anticline and syncline supplies water both to the higher elevation springs (Water Canyon, Yellow Creek and Sheep Creek) and to the Paunsaugunt Fault, then the relative discharge volumes for spring groups formed by two different structural mechanisms may be compared in order to evaluate the relative magnitude of the discharge associated with the two different hydrologic systems. Higher elevation springs are likely to have derived from migration of groundwater along relatively shallow flow paths, remaining in the subsurface for relatively shorter periods. Deeper infiltration and longer flowpaths, associated with longer periods in the subsurface, are likely to be intercepted by the Paunsaugunt Fault plane. The water chemistry of the Fault-related springs is likely to show evidence of deeper infiltration depths and longer subsurface travel times.

Sulfate concentrations in springs associated with Paunsaugunt Fault discharge fall between the higher concentrations in springs emitting from the Straight Cliffs Formation and the lower values for the Claron Formation. The springs emitting from the Straight Cliffs Formation (Riggs Spring, Iron Spring, Yellow Creek, Sheep Creek) show sulfate concentrations ranging from 49 to 900 mg/l (reported by Marine,

1963; and Plantz, 1993). Discrete depth sampling from the well installed by Marine showed sulfate concentrations ranging from 6 to 512 mg/l, with maximum concentrations at 860 foot depth or 7,150 foot elevation (364 mg/l) and 1,100 foot depth or 6,900 foot elevation (512 mg/l). In springs emitting from the Claron Formation, sulfate concentration is consistently less than 10 mg/l. Sulfate was reported in the fault-associated springs: Campbell Creek and Merrill Ranch; by Marine at concentrations of 53 and 17 mg/l for Campbell Creek and 84 mg/l for Merrill Ranch. These data suggest that discharge from the Fault related springs derives from a combination of shallow infiltrated water from the Claron Formation and deeper infiltrated water that traveled through the Straight Cliffs Formation.

5.4 Groundwater Travel Time Estimated From Pump Tests

Martin (1998) estimated from the pump test on Well #1 a well transmissivity of 8,900 ft² per day, which corresponds to a hydraulic conductivity for the Claron Formation of 150 feet per day. It is likely under a natural gradient, calculated by Martin at .0042 for the East Creek Valley, the average linear groundwater velocity is about 2 feet per day under a gradient of .0042, with a formation porosity of 0.35 (Martin, 1998 estimated Claron Formation porosity). For water discharging from Mossy Cave, this calculation suggests that over a 50 year travel time (interpreted from the Tritium age-date interpretation), water would have infiltrated at a location 6.2 miles from Mossy Cave.

The steeper topography of the highly eroded Claron Formation basins likely produces steeper hydrologic gradients than present in the alluvium filled East Creek valley. Slopes of the Claron Formation canyon walls exceed by 2 orders of magnitude those present in East Creek, suggesting flow rates potential 100 times greater than calculated for the East Creek Valley, up to 200 feet per day. Flow rates estimates of 2 to 200 feet per day likely represent the potential range of groundwater velocities likely within BCNP. Using a flow rate of 10 feet per day, five times that present at East Creek, would allow groundwater to travel the length of BCNP over the 50 year period, before discharging from Mossy Cave.

Marine (1963) conducted two pump tests subsequent to installation of the 2,000 foot well in the Yellow Creek source basin. Data collected during pump tests is not provided in his report, and further analysis of the hydrologic properties of the formations intersected by the well (the Wahweap formation and the Straight Cliffs formation) was not possible for this study.

5.5 Conceptual Model Summarized

The higher gradients and larger proportional area of the eastern side of the Park likely contribute to a larger portion of water falling on BCNP discharging to the east. The structural dip suggests that once groundwater infiltrates, it is likely to travel towards and discharge from a more northerly location. The rate of discharge is likely to be more rapid on the eastern side of the Park, due to higher topographic gradients. And, water is more likely to discharge as springs at higher elevations within the Park due to the varied lithology of the Claron formation and the underlying formations.

Spring discharge from the Claron Formation provides the majority of discharge from BCNP, based on spring discharge measurements and the relative magnitude of spring flows containing sulfate discharge (interpreted to indicate Straight Cliffs formation discharge). Significant uncertainties qualify this interpretation. The quantity of water that discharges from the western boundary of the park to the East Fork of the Sevier River is poorly defined. The contribution of Tropic Ditch infiltration (actually diverted from the East Fork drainage) to Water Canyon discharge is a very rough estimate. Water infiltrating from Tropic Ditch may contribute up to 7 percent of the discharge from BCNP, which may provide a significant amount of the estimated discharge from the Claron formation. Groundwater storage in the Straight Cliffs aquifer can not be accurately quantified with the data available for this study. Neither has the discharge from that aquifer been adequately estimated, beyond the measured discharge of the 5 springs associated with Paunsaugunt Fault-induced discharge (Campbell Creek, Merrill Ranch, Bryce, Jolley Hollow, and Dr. Goode).

6 CONCLUSIONS

The relatively uniform water chemistry measured in 1998 samples; consistently high calcium, magnesium and bicarbonate contents, reflects the dominant influence of the carbonate lithology of the Claron formation. High sulfate contents were measured in water collected from springs issuing from the Straight Cliffs formation, suggesting reaction with the marine sediments of the John Henry Member or Tibbet Canyon Member of the Straight Cliffs Formation.

While the chemistry of the water collected from Mossy Cave and Water Canyon is similar to that collected from the Tropic Ditch, there are noticeable differences that suggest Water Canyon discharge derives primarily from a different source than Tropic Ditch. The similarities derive from the fact that the dominant analytes present are representative of a carbonate influenced hydrogeologic system. The differences include the high chloride concentration, and trace amounts of aluminum present in the Tropic Ditch samples that are not present in the Water Canyon samples. Additionally, nitrate is present in the Water Canyon samples that is not evidenced in the Tropic Ditch samples.

From the existing data, it appears that discharge volumes at the northern end of the park are considerably larger than the discharge from springs emitting to the south of Sheep Creek. This observation implies that there is northward subsurface migration of groundwater flow, also suggested by Czarnowski and Marine. The northward movement is likely enhanced by the northward dipping trend of the Bryce Anticline, and continued in the northward trending syncline located to the north of the anticline. These structures potentially direct a significant water volume to the north, that likely has a primary discharge location at Water Canyon.

Discharge data available for this study was collected predominantly from springs emitting on the east side of BCNP. The single discharge measurement available for the west side, from an unnamed spring in Bridge Hollow, suggests that a significant component of the discharge from BCNP may be emitting on from the west side of the Park. Additional spring discharge data from the west side springs would

improve the estimate of the proportional amount discharged on the east side of the park, the overall understanding directions of ground movement in the park, and estimates of the proportional quantities discharging at the various locations in the BCNP vicinity.

The particularly large discharge in the Water Canyon vicinity with respect the discharge from the entire BCNP discharge is likely to be due to the combined contribution of the following sources: northward migration of groundwater in the Bryce Canyon vicinity, infiltration of precipitation in the vicinity of Water Canyon, diversion through Tropic Ditch to Water Canyon, and infiltration from Tropic Ditch discharging to springs in Water Canyon. The large discharge quantity through Water Canyon suggests that hydrologic "augmentation" by Tropic Ditch infiltration is likely. However, it is not possible to discern the proportional amounts of water contributed to Water Canyon discharge from Tropic Ditch and local infiltration with the data currently available, especially since the discharge rates used in this study to assess the proportionality of Water Canyon discharge were measured when diversion to Tropic Ditch had been terminated. The water chemistry data differences suggest predominantly different origins for the water analyzed from Tropic Ditch and water analyzed from Water Canyon. Additionally, the age date derived from the tritium content of Mossy Cave spring water indicates a subsurface travel time of over 50 years. This travel time is consistent with extended subsurface water movement, likely if water infiltrated at the south of BCNP and migrated over the length of the park before discharging at Mossy Cave. Taken together these data suggest that the contribution of Tropic Ditch infiltration is a small percentage of the overall discharge from Mossy Cave and Water Canyon.

7 RECOMMENDATIONS FOR FURTHER STUDY

7.1 Additional Discharge Measurements

The limitations of data used for estimating the hydrologic budget and the proportion of discharge from specific springs in the BCNP vicinity have been discussed previously in the report. To better assess the contribution of Tropic Ditch infiltration on Mossy Cave and Water Canyon discharge, additional flow measurements for the Mossy Cave and Water Canyon flow are recommended. Measurements should be collected in the early spring, just prior to initiation of the diversion from the Tropic Reservoir in order to measure the natural discharge from Mossy Cave with a minimal infiltration component, and at the longest possible period after infiltration has ceased. Additionally, discharge measurements should be collected periodically from Water Canyon once Tropic Ditch infiltration has begun, in order to estimate the progressive changes in discharge that may be resulting from infiltration from Tropic Ditch.

Information on the springs that issue from the West side of BCNP is scarce. Flow measurements from the west side springs and East Creek drainage would significantly improve estimates of groundwater movement on the west side of BCNP. Additional characterization and measurement of springs along the Paunsaugunt Fault, and supplemental data with which to estimate groundwater storage will improve the accuracy of the hydrologic budget for the Park.

7.2 Evaporation and Transpiration Estimates

Evaporation and transpiration are significant components of a hydrologic budget. These processes were not included in estimates for this study. Additional climate data should be collected to improve the calculated water volumes that are removed from the BCNP hydrologic system by these processes. Estimates using simplifying assumptions to calculation of evapotranspiration for the Park, or numerical modeling using the specific measurement of Park meteorology and over small time (daily) increments would significantly improve the accuracy of the hydrologic budget as currently proposed.

7.3 Groundwater Model

Improvement to the accuracy of the hydrologic budget estimates contained herein require the use of a numerical model to simulate groundwater movement and discharge at BCNP. Better estimates of the annual changes in groundwater storage, Paunsaugut Fault related spring discharge, groundwater flow through the northern boundary of the park, and discharge from the west side of the Park to East Fork would particularly benefit from numerical modeling. Depending upon accuracy and information required for future BCNP water resource management decisions, compilation of a numerical model may provide a valuable tool.

7.4 Age Dating of Groundwater

To improve the conceptual model proposed, additional measurement of groundwater dates using isotope methods in spring water should be collected. The age of groundwater emitting from springs, and the associated subsurface travel time was established only for one spring for this study, and defined with respect to a minimum subsurface travel time for two others. These data added significantly to the overall conceptual model proposed for the hydrogeology of the Park. Age dating of groundwater would be particularly valuable for springs discharging in the northeast area of the Park: Mossy Cave, Yellow Creek, and Sheep Creek. Additionally, Paunsaugut Fault related springs age dates would provide insight into the groundwater storage component of the hydrologic budget.

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Figure 2.1 Sample Collection Locations
(continued on following page)

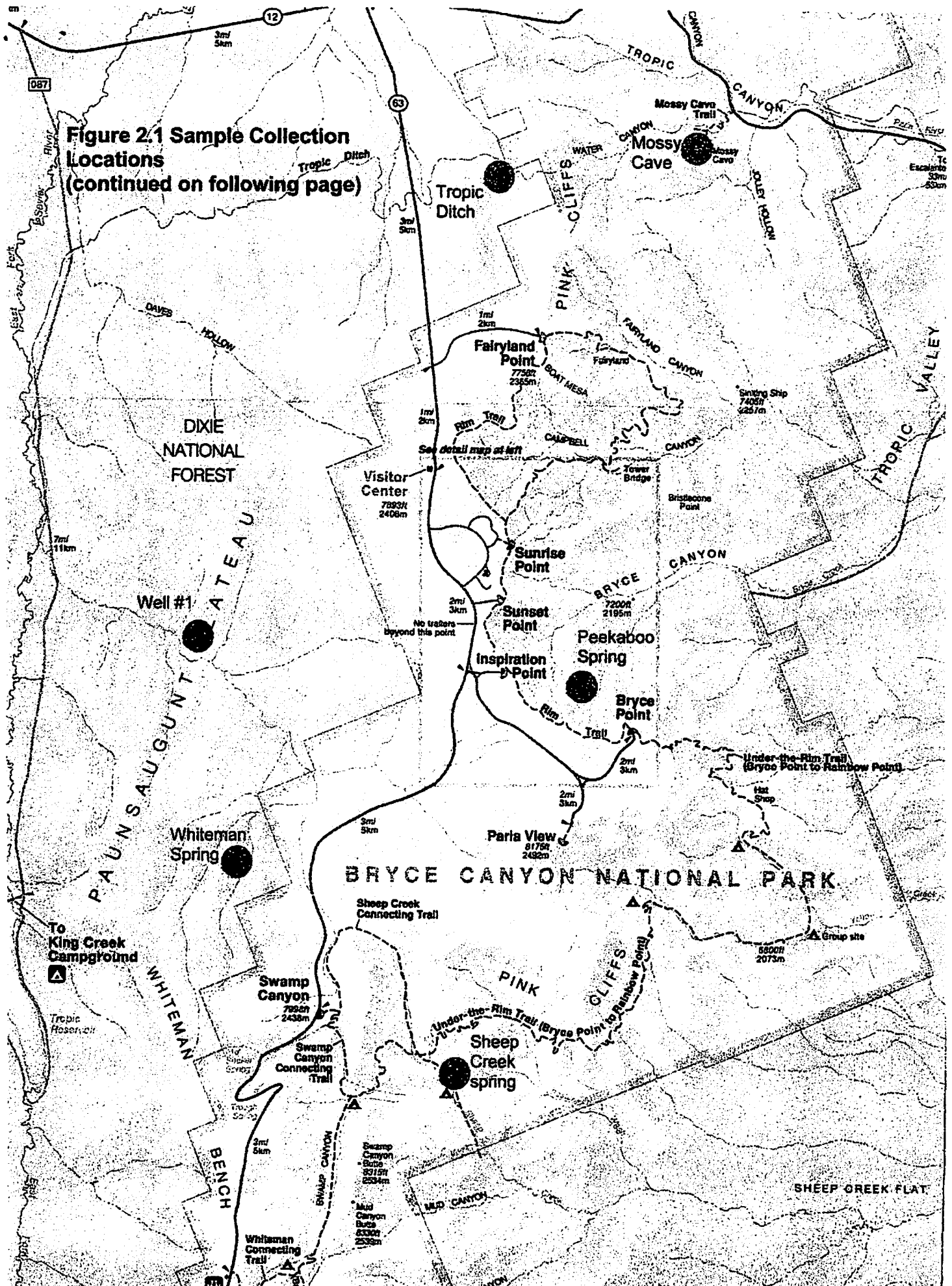


Figure 2.1 Sample Collection Locations (page 2 of 2)

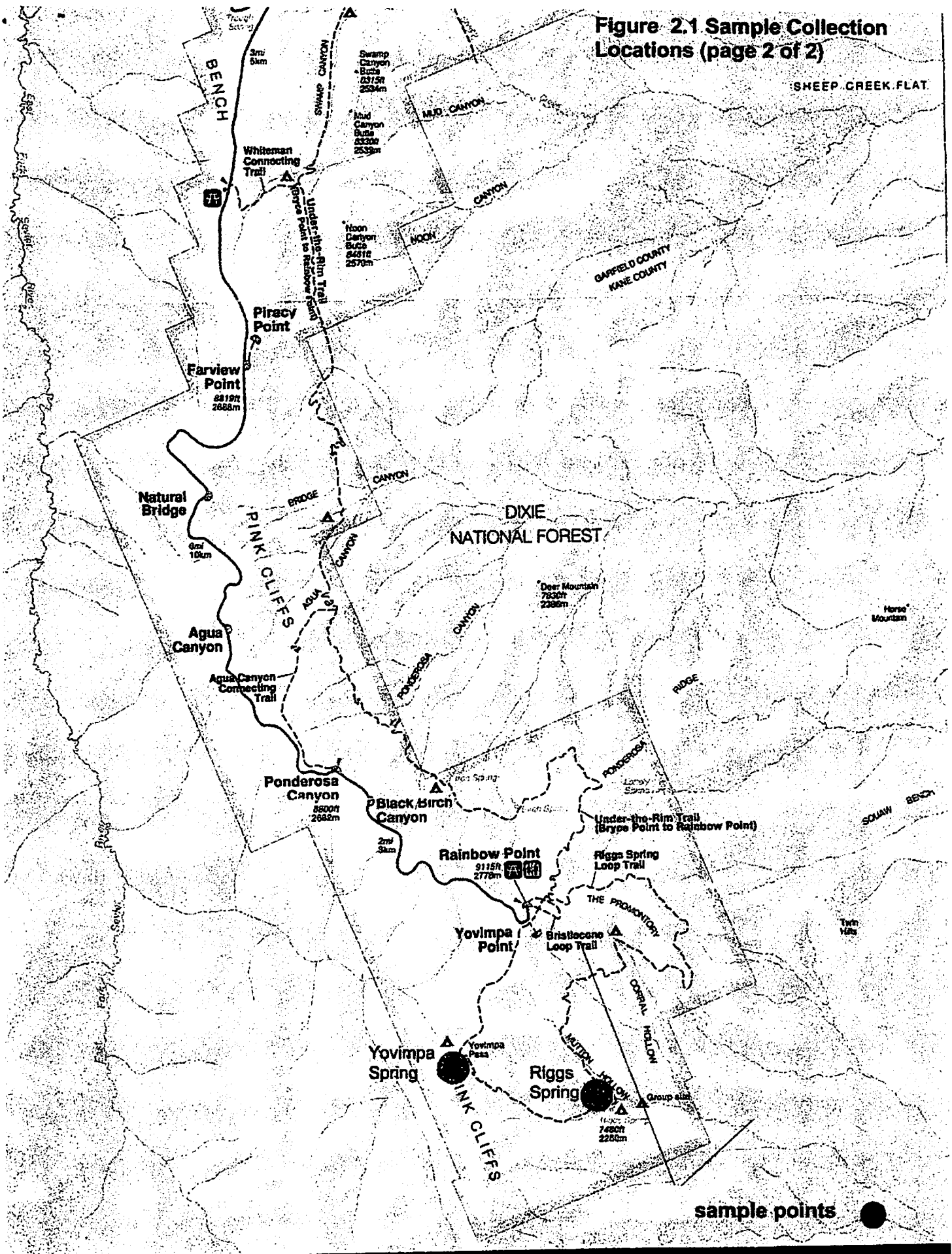
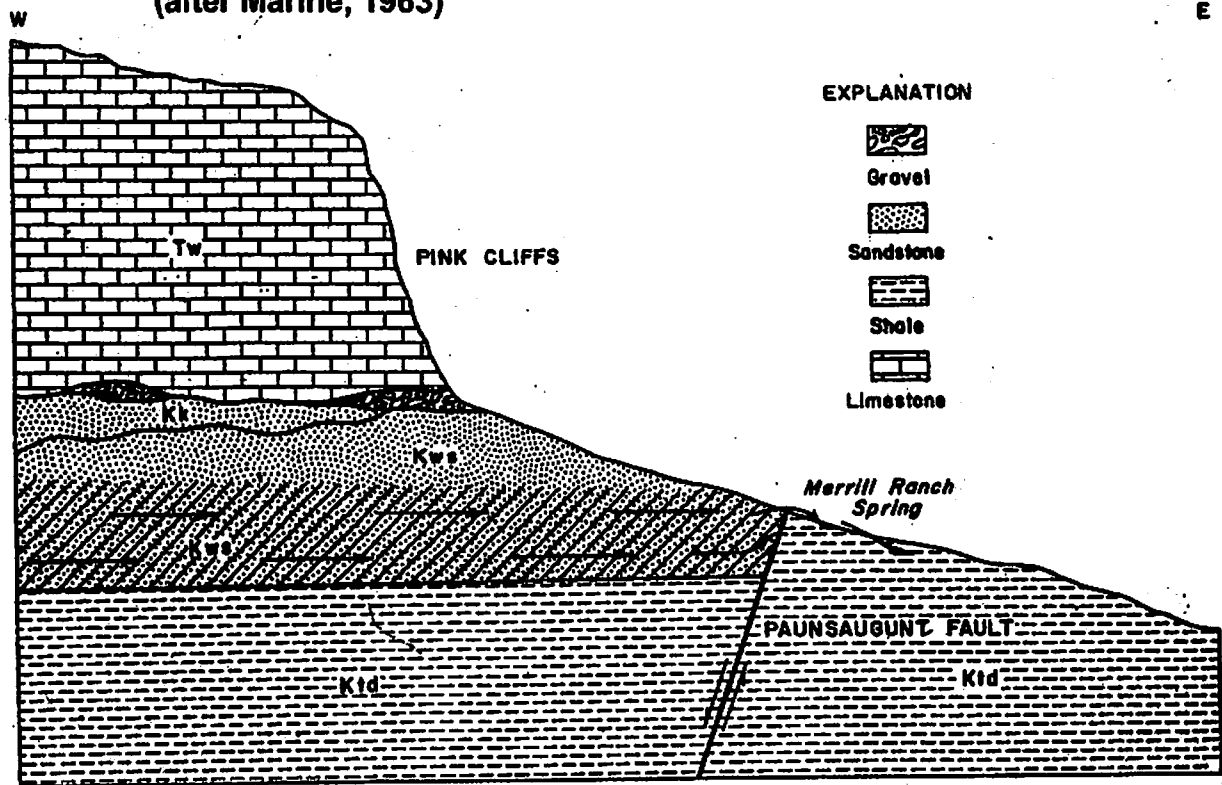


**Figure 5.1 Generalized Diagram of Bryce Canyon National Park
Geology and Paunsaugunt Fault-Induced Spring Discharge
(after Marine, 1963)**



Tw = Claron Formation

Kk = Kaiparowits Formation

Kws = Wahweap Sandstone and Straight Cliffs Formation

Ktd = Tropic Shale and Dakota Sandstone

Table 2.1 Sample Locations

Sample Name	Sample Location	Date	Source	Lithologic Unit	elevation
Whiteman	Whiteman Spring	11/2/98	diffuse spring	Claron fmtn	8160
Tropic	Tropic Ditch	11/2/98	East Fork Sevier River	NA	7640
Well #1	Bryce Park Well field	11/3/98	groundwater	alluvium/Claron fmtn	7695 - 7775
Yovimpa	Yovimpa Spring	11/3/98	spring	Claron fmtn	8320
Riggs	Riggs Spring	11/3/98	spring	Straight Cliffs fmtn	7500
Mossy Cave	Mossy Cave Spring	11/4/98	diffuse spring	Claron fmtn	6980
Water Canyon	Water Canyon stream	11/4/98	stream flow	Claron fmtn	6880
Falls Pool	Water Canyon stream	11/4/98	stream flow	Claron fmtn	6840
Peekaboo	Peekaboo Spring	11/4/98	spring	Claron fmtn	7600
Sheep Creek	Sheep Creek seep	11/5/98	seep	Straight Cliffs fmtn	7560
Still Spring *	Tropic Ditch	11/5/98	East Fork Sevier River	NA	7640

* sample collected at same location as Tropic sample for QA purposes