## SOILS

Map Unit Name
(Series and Phase): ____________________ Drainage Class: ________
Field Observations
Taxonomy (Subgroup): ____________________ Confirm Mapped Type? Yes No

**Profile Description:**

| Depth (inches) | Horizon | Matrix Color (Munsell Moist) | Mottle Colors (Munsell Moist) | Mottle Abundance/Contrast | Texture, Concretions, Structure, etc. |
|---|---|---|---|---|---|
| 8" | A | — | — | — | Silty-SAND |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

Hydric Soil Indicators:

- ___ Histosol
- ___ Histic Epipedon
- ___ Sulfidic Odor
- ___ Aquic Moisture Regime
- ___ Reducing Conditions
- ___ Gleyed or Low-Chroma Colors
- ___ Concretions
- ___ High Organic Content in Surface Layer in Sandy Soils
- ___ Organic Streaking in Sandy Soils
- ___ Listed on Local Hydric Soils List
- ___ Listed on National Hydric Soils List
- ___ Other (Explain in Remarks)

Remarks: No indicators present. SANDY, with large grain size.

## WETLAND DETERMINATION

| | | |
|---|---|---|
| Hydrophytic Vegetation Present? | Yes **(No)** (Circle) | |
| Wetland Hydrology Present? | **(Yes)** No | (Circle) |
| Hydric Soils Present? | Yes **(No)** | Is this Sampling Point Within a Wetland? Yes **(No)** |

Remarks: NON-WETland.

Approved by HQUSACE 3/92

DATA FORM
ROUTINE WETLAND DETERMINATION
(1987 COE Wetlands Delineation Manual)

| | |
|---|---|
| Project/Site: Moon Camp<br>Applicant/Owner:<br>Investigator: R. Beck / T. Smith | Date: 8/15/02<br>County: SB<br>State: CA |
| Do Normal Circumstances exist on the site? (Yes) No<br>Is the site significantly disturbed (Atypical Situation)? Yes (No)<br>Is the area a potential Problem Area? Yes (No)<br>(If needed, explain on reverse.) | Community ID: —<br>Transect ID: —<br>Plot ID: 3 |

## VEGETATION

| Dominant Plant Species | Stratum | Indicator | Dominant Plant Species | Stratum | Indicator |
|---|---|---|---|---|---|
| 1. Jeffery Pine | Tree | — | 9. | | |
| 2. | | | 10. | | |
| 3. | | | 11. | | |
| 4. | | | 12. | | |
| 5. | | | 13. | | |
| 6. | | | 14. | | |
| 7. | | | 15. | | |
| 8. | | | 16. | | |

Percent of Dominant Species that are OBL, FACW or FAC (excluding FAC-). ______

Remarks: open areas, upland habitat / dry.

## HYDROLOGY

___ Recorded Data (Describe in Remarks):
- ___ Stream, Lake, or Tide Gauge
- ___ Aerial Photographs
- ___ Other

X No Recorded Data Available

Field Observations:

Depth of Surface Water: — (in.)

Depth to Free Water in Pit: — (in.)

Depth to Saturated Soil: — (in.)

Wetland Hydrology Indicators:

Primary Indicators:
- ___ Inundated
- ___ Saturated in Upper 12 Inches
- ___ Water Marks
- ___ Drift Lines
- X Sediment Deposits
- ___ Drainage Patterns in Wetlands

Secondary Indicators (2 or more required):
- ___ Oxidized Root Channels in Upper 12 Inches
- ___ Water-Stained Leaves
- ___ Local Soil Survey Data
- ___ FAC-Neutral Test
- ___ Other (Explain in Remarks)

Remarks: No flow present. Sediment, larger rocks observed, rocks on small banks. "Y" in northern drainage.

## SOILS

Map Unit Name
(Series and Phase): ______ Drainage Class: ______
Field Observations
Taxonomy (Subgroup): ______ Confirm Mapped Type? Yes No

Profile Description:

| Depth (inches) | Horizon | Matrix Color (Munsell Moist) | Mottle Colors (Munsell Moist) | Mottle Abundance/Contrast | Texture, Concretions, Structure, etc. |
|---|---|---|---|---|---|
| 8" | A | — | — | — | Silty-SAND/SAND |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

Hydric Soil Indicators:

- ___ Histosol
- ___ Histic Epipedon
- ___ Sulfidic Odor
- ___ Aquic Moisture Regime
- ___ Reducing Conditions
- ___ Gleyed or Low-Chroma Colors
- ___ Concretions
- ___ High Organic Content in Surface Layer in Sandy Soils
- ___ Organic Streaking in Sandy Soils
- ___ Listed on Local Hydric Soils List
- ___ Listed on National Hydric Soils List
- ___ Other (Explain in Remarks)

Remarks: No indicators present.

## WETLAND DETERMINATION

Hydrophytic Vegetation Present? Yes **(No)** (Circle)
Wetland Hydrology Present? **(Yes)** No
Hydric Soils Present? Yes **(No)**

Is this Sampling Point Within a Wetland? (Circle) Yes **(No)**

Remarks: Non-Wetland.

Approved by HQUSACE 3/92

DATA FORM
ROUTINE WETLAND DETERMINATION
(1987 COE Wetlands Delineation Manual)

| | |
|---|---|
| Project/Site: Moon Camp<br>Applicant/Owner:<br>Investigator: R. Beck / T. Smith | Date: 3/15/02<br>County: S.B.<br>State: CA |
| Do Normal Circumstances exist on the site? (Yes) No<br>Is the site significantly disturbed (Atypical Situation)? Yes (No)<br>Is the area a potential Problem Area? Yes (No)<br>(If needed, explain on reverse.) | Community ID: —<br>Transect ID: —<br>Plot ID: 2 |

## VEGETATION

| Dominant Plant Species | Stratum | Indicator | Dominant Plant Species | Stratum | Indicator |
|---|---|---|---|---|---|
| 1. Jeffery Pine | Tree | — | 9. | | |
| 2. | | | 10. | | |
| 3. | | | 11. | | |
| 4. | | | 12. | | |
| 5. | | | 13. | | |
| 6. | | | 14. | | |
| 7. | | | 15. | | |
| 8. | | | 16. | | |

Percent of Dominant Species that are OBL, FACW or FAC (excluding FAC-). ____

Remarks:
upland habitat/dry

## HYDROLOGY

| | |
|---|---|
| ___ Recorded Data (Describe in Remarks):<br>___ Stream, Lake, or Tide Gauge<br>___ Aerial Photographs<br>___ Other<br>✓ No Recorded Data Available<br><br>Field Observations:<br>Depth of Surface Water: — (in.)<br>Depth to Free Water in Pit: — (in.)<br>Depth to Saturated Soil: — (in.) | Wetland Hydrology Indicators:<br>Primary Indicators:<br>___ Inundated<br>___ Saturated in Upper 12 Inches<br>___ Water Marks<br>___ Drift Lines<br>X Sediment Deposits<br>___ Drainage Patterns in Wetlands<br>Secondary Indicators (2 or more required):<br>___ Oxidized Root Channels in Upper 12 Inches<br>___ Water-Stained Leaves<br>___ Local Soil Survey Data<br>___ FAC-Neutral Test<br>___ Other (Explain in Remarks) |

Remarks: No flow present. Sediment rock observed. Small banks, Pine Needle ground cover.

## SOILS

Map Unit Name
(Series and Phase): ______________________ Drainage Class: ________
Field Observations
Taxonomy (Subgroup): ______________________ Confirm Mapped Type? Yes No

**Profile Description:**

| Depth (inches) | Horizon | Matrix Color (Munsell Moist) | Mottle Colors (Munsell Moist) | Mottle Abundance/Contrast | Texture, Concretions, Structure, etc. |
|---|---|---|---|---|---|
| 8" | A | — | — | — | Silty-Sand |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

Hydric Soil Indicators:

- ___ Histosol
- ___ Histic Epipedon
- ___ Sulfidic Odor
- ___ Aquic Moisture Regime
- ___ Reducing Conditions
- ___ Gleyed or Low-Chroma Colors
- ___ Concretions
- ___ High Organic Content in Surface Layer in Sandy Soils
- ___ Organic Streaking in Sandy Soils
- ___ Listed on Local Hydric Soils List
- ___ Listed on National Hydric Soils List
- ___ Other (Explain in Remarks)

Remarks:
No indicators present.

## WETLAND DETERMINATION

| | | |
|---|---|---|
| Hydrophytic Vegetation Present? | Yes **(No)** | (Circle) |
| Wetland Hydrology Present? | **(Yes)** No | |
| Hydric Soils Present? | Yes **(No)** | |

(Circle)
Is this Sampling Point Within a Wetland? Yes **(No)**

Remarks:
Non wetland.

DATA FORM
ROUTINE WETLAND DETERMINATION
(1987 COE Wetlands Delineation Manual)

| | |
|---|---|
| Project/Site: Moon Camp<br>Applicant/Owner:<br>Investigator: R. Beck / T. Smith | Date: 3/15/02<br>County: SB<br>State: CA |
| Do Normal Circumstances exist on the site? (Yes) No<br>Is the site significantly disturbed (Atypical Situation)? Yes (No)<br>Is the area a potential Problem Area? Yes (No)<br>(If needed, explain on reverse.) | Community ID: —<br>Transect ID: —<br>Plot ID: 4 |

## VEGETATION

| Dominant Plant Species | Stratum | Indicator | Dominant Plant Species | Stratum | Indicator |
|---|---|---|---|---|---|
| 1. Jeffery Pine | Tree | — | 9. | | |
| 2. Upland Shrubs | Shrub | — | 10. | | |
| 3. | | | 11. | | |
| 4. | | | 12. | | |
| 5. | | | 13. | | |
| 6. | | | 14. | | |
| 7. | | | 15. | | |
| 8. | | | 16. | | |

Percent of Dominant Species that are OBL, FACW or FAC (excluding FAC-). ______

Remarks: upland habitat

## HYDROLOGY

___ Recorded Data (Describe in Remarks):
- ___ Stream, Lake, or Tide Gauge
- ___ Aerial Photographs
- ___ Other

X No Recorded Data Available

Field Observations:

Depth of Surface Water: — (in.)

Depth to Free Water in Pit: — (in.)

Depth to Saturated Soil: — (in.)

Wetland Hydrology Indicators:

Primary Indicators:
- ___ Inundated
- ___ Saturated in Upper 12 Inches
- ___ Water Marks
- ___ Drift Lines
- X Sediment Deposits
- ___ Drainage Patterns in Wetlands

Secondary Indicators (2 or more required):
- ___ Oxidized Root Channels in Upper 12 Inches
- ___ Water-Stained Leaves
- ___ Local Soil Survey Data
- ___ FAC-Neutral Test
- ___ Other (Explain in Remarks)

Remarks: Appeared to bed fed by outfall to the north.

## SOILS

Map Unit Name
(Series and Phase): ______ Drainage Class: ______
Field Observations
Taxonomy (Subgroup): ______ Confirm Mapped Type? Yes No

Profile Description:

| Depth (inches) | Horizon | Matrix Color (Munsell Moist) | Mottle Colors (Munsell Moist) | Mottle Abundance/Contrast | Texture, Concretions, Structure, etc. |
|---|---|---|---|---|---|
| 8' | A | – | – | – | Silty-Sand. |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

Hydric Soil Indicators:

- ___ Histosol
- ___ Histic Epipedon
- ___ Sulfidic Odor
- ___ Aquic Moisture Regime
- ___ Reducing Conditions
- ___ Gleyed or Low-Chroma Colors
- ___ Concretions
- ___ High Organic Content in Surface Layer in Sandy Soils
- ___ Organic Streaking in Sandy Soils
- ___ Listed on Local Hydric Soils List
- ___ Listed on National Hydric Soils List
- ___ Other (Explain in Remarks)

Remarks:
No indicators present.

## WETLAND DETERMINATION

Hydrophytic Vegetation Present? Yes (No) (Circle)
Wetland Hydrology Present? (Yes) No
Hydric Soils Present? Yes (No)

(Circle)
Is this Sampling Point Within a Wetland? (Yes) No

Remarks:
Non-Wetland.

Approved by HQUSACE 3/92

# 15.11 Geohydrologic Evaluation

# Focused Geohydrologic Evaluation of the Maximum Perennial Yield of the North Shore and Grout Creek Hydrologic Subunit Tributary Subareas

*Prepared for: City of Big Bear Lake Department of Water and Power*

## December 2, 2003


GEOSCIENCE Support Services, Inc.
Tel: (909) 920-0707
Fax: (909) 920-0403
Mailing: P. O. Box 220, Claremont, CA 91711
1326 Monte Vista Ave., Suite 3, Upland, CA 91786
email: email@geoscience-water.com

# FOCUSED GEOHYDROLOGIC EVALUATION OF MAXIMUM PERENNIAL YIELD FOR THE NORTH SHORE AND GROUT CREEK HYDROLOGIC SUBUNITS

## CONTENTS

## CONTENTS
## (Continued)

## FIGURES

# TABLES

# APPENDIX

# FOCUSED GEOHYDROLOGIC EVALUATION OF MAXIMUM PERENNIAL YIELD FOR THE NORTH SHORE AND GROUT CREEK HYDROLOGIC SUBUNITS

## 1.0 EXECUTIVE SUMMARY

The Big Bear Lake Watershed, located in the San Bernardino Mountains of western San Bernardino County, California has previously been divided into seven hydrologic subunits based on surface water drainage divides. Two of the hydrologic subunits, the North Shore and Grout Creek Subunits, extend across most of the northern portion of Big Bear Lake. Although these subunits can be categorized as independent surface drainage catchments, their large size and/or elongated east-west extent warrants further subdivision to distinguish available ground water resources in the eastern portion from available ground water resources in the western portion. This report presents a focused geohydrologic evaluation of the maximum perennial yield of the North Shore and Grout Creek subunits that includes dividing each subunit into smaller tributary subareas.

Maximum perennial yield was evaluated in the context of the total average annual ground water recharge within the North Shore and Grout Creek subunits. Ground water recharge is the total amount of water that reaches the aquifer (i.e. ground water reservoir) through natural processes, such as deep percolation of precipitation falling on the land surface and infiltration beneath flowing stream channels. In the development of ground water resources for municipal supply, however, not all of the natural recharge that any given aquifer receives on an average annual basis can be developed.

Maximum perennial yield is distinguished from average annual ground water recharge through the following definition:

> *The maximum quantity of ground water perennially available if all possible methods and sources are developed for recharging the basin. This quantity depends on the amount of water economically, legally, and politically available to the organization or agency managing the basin (Todd, 1980).*

By definition, the maximum perennial yield is some portion (i.e. subset) of the total amount of ground water recharge that the aquifers receive from precipitation on an average annual basis. Not all of the water that reaches the aquifer can be developed for beneficial use because either it is not economically feasible, or there is no legal right to the water, or political constraints prevent or inhibit development.

Average annual ground water recharge estimates were assigned to smaller tributary subareas, which were determined from surface drainage divides within the larger hydrologic subunits. The North Shore Subunit was subdivided into six tributary subareas (A through F) and the Grout Creek Subunit was subdivided into four tributary subareas (A through D). The boundaries of the tributary subareas represent surface water drainage divides, which, for most of the tributary subareas also represent ground water flow divides. Exceptions include the margins of Big Bear Lake and in the southeast portion of the North Shore Subunit, where the ground water within one subarea/subunit can be in hydraulic communication with adjacent subareas/subunits.

Average annual ground water recharge was estimated for each tributary subarea using a watershed hydrologic model and by estimating ground water underflow (conducted for the alluvial portion of the Grout Creek Subunit only). When possible, measured data was used as input for the analysis of ground water recharge. Measured data included:

- Long-term precipitation records from weather stations within the Big Bear Lake watershed,
- Evapotranspiration data from evaporation pans and weather stations within the watershed,
- Ground water levels, and
- Ground water production.

However, most of the input parameters that are required for a detailed evaluation of the average annual ground water recharge had to be estimated or assumed from data collected outside the Grout Creek and North Shore subunits or outside the Big Bear Lake Watershed due to lack of measured data in the area. Although the assumed values are published and are from reliable sources (i.e. the U.S. Environmental Protection Agency, United States Geological Survey, etc.), they are not specific to the area of interest. Numerous additional monitoring features can be developed to collect the data necessary to refine the ground water recharge estimates. However, priority should be given to the construction of monitoring wells and the development of a reliable ground water level baseline for the tributary subareas.

The results of the ground water recharge analysis for the North Shore Subunit are as follows:

**Summary of Ground Water Recharge Results**
**North Shore Tributary Subareas**

| Tributary Subarea | Area [acres] | Annual Precipitation [inches] | Average Annual Ground Water Recharge - Low Estimate [acre-ft/yr] | Average Annual Ground Water Recharge - High Estimate [acre-ft/yr] | Average of Ground Water Recharge Estimate Range [acre-ft/yr] |
|---|---|---|---|---|---|
| A | 247 | 27.87 | 14 | 44 | 29 |
| B | 720 | 25.45 | 36 | 110 | 73 |
| C | 828 | 23.01 | 37 | 107 | 72 |
| D | 558 | 21.45 | 22 | 63 | 43 |
| E | 392 | 20.01 | 15 | 39 | 27 |
| F | 814 | 18.27 | 23 | 66 | 44 |

Based on the analyses presented in this report, the following have been concluded regarding the maximum perennial yield of the North Shore Hydrologic Subunit:

- The North Shore Hydrologic Subunit can be conveniently subdivided into six tributary subareas (A through F) based on surface water drainage divides;

- The revised range of average annual ground water recharge for the North Shore Hydrologic Subunit as a whole is approximately 150 to 430 acre-ft/yr with a midpoint of approximately 290 acre-ft/yr.

- The midpoint of the estimated range of average annual ground water recharge (290 acre-ft/yr) is considered a good estimate of maximum perennial yield for the North Shore Hydrologic Subunit, given the available data. The midpoint of the range is approximately 4.5 percent of precipitation for the subunit which is within the range of accepted recharge estimates for other ground water basins in southern California (3 to 7 percent; Metropolitan Water District of Southern California (MWD), 1999; Daniel B. Stevens, 1996).

- The revised perennial yield of **290 acre-ft/yr** is slightly higher than the previous perennial yield value of 260 acre-ft/yr from the GEOSCIENCE, 2001 report, primarily as a result of the use of an updated EPA input parameter list for the watershed model and the consideration of the bedrock aquifer as a viable source of ground water supply;

- The maximum perennial yield for individual tributary subareas within the North Shore Subunit range from 27 acre-ft/yr (Subarea E) to 73 acre-ft/yr (Subarea B); and

- Additional ground water monitoring and geohydrologic data collection are required in each individual subarea to manage the ground water resources in the area as it is developed in the future.

The results of the ground water recharge analysis for the Grout Creek Subunit are as follows:

**Summary of Ground Water Recharge Results**
**Grout Creek Tributary Subareas**

| Tributary Subarea | Area (acres) | Annual Precipitation (inches) | Average Annual Ground Water Recharge - Low Estimate (acre-ft/yr) | Average Annual Ground Water Recharge - High Estimate (acre-ft/yr) | Average of Ground Water Recharge Estimate Range (acre-ft/yr) |
|---|---|---|---|---|---|
| A | 1,074 | 33.44 | 74 | 249 | 161 |
| B | 850 | 29.01 | 50 | 160 | 105 |
| C | 1,668 | 29.93 | 104 | 331 | 217 |
| D | 592 | 26.74 | 32 | 99 | 66 |

For the Grout Creek Hydrologic Subunit, the following is concluded:

- The Grout Creek Hydrologic Subunit can be conveniently subdivided into four tributary subareas (A through D) based on surface water drainage divides;
- The revised range of average annual recharge for the Grout Creek Hydrologic Subunit as a whole (Tributary Subareas A through D) is approximately 260 to 840 acre-ft/yr with a midpoint of approximately 550 acre-ft/yr. However, ground water resources in Subareas A and B of the Grout Creek Subunit are not currently practical to develop because they are remote and are located on land under the jurisdiction of the USFS;
- Due to the cost and political limitations associated with ground water development in Subareas A and B, it is currently recommended to use the sum of the midpoint recharge estimates for tributary Subareas C and D as the maximum perennial yield for the Grout Creek Subunit. This results in a maximum perennial yield for the Grout Creek Subunit of **283 acre-ft/yr**;
- The revised perennial yield is higher than the previous perennial yield value of

200 acre-ft/yr from the GEOSCIENCE, 2001 report, primarily as a result of the use of an updated EPA input parameter list for the watershed model and the consideration of the bedrock aquifer as a viable source of ground water supply;

- The maximum perennial yield for individual tributary subareas within the Grout Creek Subunit range from 66 acre-ft/yr (Subarea D) to 217 acre-ft/yr (Subarea C).

Given the possible range of recharge for the North Shore and Grout Creek Hydrologic Subunits, and correspondingly the range of recharge for the individual tributary subareas within each subunit, it is recommended that development planning for tributary subareas be initially based on the maximum perennial yield estimates described above. However, as ground water production is initiated in each tributary subarea, it will be very important to monitor ground water levels in dedicated non-pumping monitoring wells located in each tributary subarea from which ground water is extracted.

The ground water recharge analysis is based on long-term precipitation records. However, short-term periods (5 to 10 years) of relatively low precipitation have been observed throughout the period of record. These short-term periods of low precipitation are anticipated to have a significant impact on the ground water levels in the North Shore and Grout Creek Hydrologic Subunits because the storage capacity of the ground water reservoir is relatively small. For this reason, future ground water production, and development, in each tributary subunit should rely more on established ground water level thresholds than the perennial yield estimates.

# 2.0 INTRODUCTION

## 2.1 Background

The Big Bear Lake Watershed, located in the San Bernardino Mountains of western San Bernardino County, California (see Figure 1), has previously been divided into seven hydrologic subunits based on surface water drainage divides (Glenn A. Brown & Associates, 1974; GEOSCIENCE, 2001). These hydrologic subunits include: Gray's Landing, Mill Creek, Village, Rathbone, Division, North Shore and Grout Creek. The North Shore Hydrologic Subunit extends across most of the northern portion of Big Bear Lake (see Figure 2). Although the subunit can be categorized as one surface drainage catchment, its elongated east-west extent warrants further subdivision to distinguish available ground water resources in the eastern portion from available ground water resources in the western portion. Likewise, the large size of the Grout Creek Subunit, also located on the northern side of Big Bear Lake, also warranted further subdivision.

As a follow-up study to the most recent Maximum Perennial Yield analysis for the Big Bear Lake area (GEOSCIENCE, 2001), GEOSCIENCE conducted a focused evaluation of the maximum perennial yield of the North Shore and Grout Creek Hydrologic Subunits. The evaluation involved dividing the larger subunits into multiple tributary subareas and assigning perennial yield values to each of the subareas.

## 2.2 Purpose and Scope

The purpose of this report is to summarize the methodology, analysis, and findings of a focused evaluation of maximum perennial yield for the North Shore and Grout Creek Hydrologic Subunits of the Big Bear Lake Watershed. The scope of this evaluation included:

1. Updating the existing geohydrologic database for these hydrologic subunits,
2. Dividing the North Shore and Grout Creek Hydrologic Subunits into multiple tributary subareas,
3. Evaluating the maximum perennial yield of each tributary subareas using independent methods, and
4. Preparing this report of findings from the analysis.

The geohydrologic database was updated with well production and ground water level data from the Big Bear Lake Department of Water and Power (BBDWP) and precipitation data from the San Bernardino County Flood Control District. In addition, the following reports were consulted for the analysis and in the preparation of this report:

- Re-evaluation of the Maximum Perennial Yield Big Bear Lake Watershed and a Portion of Baldwin Lake, GEOSCIENCE, 2001.

- Geohydrological Investigation of the Moon Camp Area, Big Bear Valley, California, GEOSCIENCE, 2001.

- Estimating Hydrology and Hydraulic Parameters for HSPF, United States Environmental Protection Agency, 2000.

- An Interactive Database of HSPF Model Parameters, Version 1.0, United States Environmental Protection Agency, 1999.

- Geohydrology of Big Bear Lake and Baldwin Lake Drainage Areas, Glenn A. Brown & Associates, 1974.

## 3.0 METHODOLOGY

Maximum perennial yield is defined as:

> *The maximum quantity of ground water perennially available if all possible methods and sources are developed for recharging the basin. This quantity depends on the amount of water economically, legally, and politically available to the organization or agency managing the basin (Todd, 1980).*

By definition, the maximum perennial yield is some portion (i.e. subset) of the total amount of ground water recharge that the aquifers receive from precipitation on an average annual basis. Not all of the water that reaches the ground water aquifer can be developed for beneficial use because either it is not economically feasible, or there is no legal right to the water, or political constraints prevent or inhibit development.

Estimating the average annual ground water recharge involves relating geohydrologic and ground water basin operational factors in a quantitative form. It requires a detailed understanding of the basin's inflow terms (including all precipitation, infiltration, and other recharge), and outflow terms (including ground water extraction, evapotranspiration, and losses to the surface and/or adjacent ground water reservoirs). When possible, inflow and outflow terms are obtained from measured data, such as:

- Long-term precipitation records from weather stations within the Big Bear Lake watershed,
- Evapotranspiration data from evaporation pans and weather stations within the watershed,
- Ground water levels, and
- Ground water production.

However, most of the factors that affect the inflow and outflow terms that are required for a detailed evaluation of the ground water recharge have to be estimated or assumed from data collected outside the Grout Creek and North Shore subunits or outside the Big Bear Lake Watershed. Although the values are published and are from reliable sources (i.e. the U.S. Environmental Protection Agency, United States Geological Survey, etc.), they are not specific to the area of interest.

The lack of measured hydrologic data in the Grout Creek and North Shore Hydrologic subunits and corresponding assumptions necessary to estimate average annual ground water recharge (from which the maximum perennial yield can be evaluated) results in a relatively wide range of possible ground water recharge values for any given hydrologic subunit or tributary subarea. As more hydrologic information is collected, the range in ground water recharge estimates will narrow. Hydrologic data that, if measured in the Grout Creek and North Shore areas, would have the greatest impact on the ground water recharge/perennial yield estimates for the subunits and tributary subareas (and the Big Bear Lake Watershed as a whole) would include:

- Ground water monitoring wells in each of the tributary subareas,
- Additional information from private wells in each of the tributary subareas,
- Stream flow discharge (as would be measured from stream gages) for the major tributaries in the Grout Creek and North Shore subunits;
- Additional weather stations in the Grout Creek and North Shore subunits that would be equipped with instrumentation to measure:
  - Precipitation (including snow accumulation),
  - Ambient air temperature,
  - Vertical and horizontal wind speed and direction,
  - Relative humidity,

- Barometric pressure,
- Water vapor density,
- Solar radiation,
- Soil temperature,
- Soil heat flux, and
- Soil moisture content;

- Evaporation pans at each weather station location; and

- Pumping tests in selected wells to obtain aquifer parameters.

It should be noted that surface water infiltration testing currently being conducted in the Big Bear Valley as part of the Big Bear Area Regional Wastewater Agency Groundwater Replenishment Study will also provide valuable information on the recharge characteristics of the sediments between the land surface and ground water table.

Where possible, multiple methods were utilized to estimate the average annual ground water recharge of the various tributary subareas of the North Shore and Grout Creek Hydrologic Subunits. The methods considered were:

- Ground Water Underflow Calculation - Darcian Flow
- Watershed Model

The methods employed for the analysis are described in more detail in the following subsections.

### 3.1 Delineation of Tributary Subareas

Prior to conducting the maximum perennial yield analysis, the North Shore and Grout Creek Hydrologic Subunits were subdivided into multiple tributary subareas (see Figure 2). Tributary subareas represent smaller surface water drainage subbasins within the larger hydrologic subunit. Thus, the boundaries of the subareas represent surface water drainage divides. For most of the hydrologic subunits, it is assumed that the surface water drainage divides also represent ground water flow divides, particularly in areas where bedrock is exposed at the ground surface. However, in areas of the North Shore and Grout Creek subunits where the surface water drainage boundaries transect unconsolidated alluvium, which occurs on the lower slopes and in the southeast portion of the North Shore Subunit, the drainage divides do not necessarily represent ground water flow divides. In these areas, the ground water within one subarea/subunit can be in hydraulic communication with adjacent subareas/subunits.

The North Shore Subunit was subdivided into six tributary subareas (A through E) and the Grout Creek Subunit was subdivided into four tributary subareas (A through D). The subareas were determined through hydrological analysis of a digital elevation model using a Geographic Information System (GIS). Tributary subareas in the North Shore Subunit range in area from 247 to 828 acres with a total subunit area of 3,559 acres. Tributary subareas in the Grout Creek Subunit range in area from 592 to 1,668 acres with a total subunit area of 4,184 acres.

### 3.2 Ground Water Underflow Calculation – Darcian Flow

The Underflow Method (Roscoe-Moss, 1990) provides an estimate of ground water recharge moving through permeable formations (i.e. aquifers) within the watershed. This method is based on Darcy's Law and was determined only for the alluvial aquifers with available data. In this case, only Grout Creek has enough available information to perform an estimate of ground water underflow.

The underflow calculation utilized average transmissivity, aquifer width, and hydraulic gradient to solve Darcy's Law through the use of a flow net. Transmissivity values for the underflow calculations were obtained from pumping tests and lithologic data of wells within and/or immediately adjacent to each respective flow net. Hydraulic gradient and aquifer width were obtained from a ground water level contour map.

It should be noted that the underflow calculation only accounts for outflow in the alluvial aquifer and does not account for outflow through the bedrock in the subunit. It is assumed that some outflow occurs within the bedrock aquifer, which explains why the underflow estimate for the Grout Creek Subunit is lower than the ground water recharge estimate from the watershed model (described below). Previous perennial yield estimates (GEOSCIENCE, 2001) have been based on the assumption that production of water from the bedrock aquifer is not as economically feasible as production of water from the alluvial aquifer.

### 3.3 Watershed Model

Another method used to estimate the average annual ground water recharge was through the use of a watershed model. The watershed model is a computer tool that assists in solving the water balance, or hydrologic budget, for each tributary subarea. The water balance takes into account all of the quantifiable hydrologic variables that affect the water resources of the catchment. These variables include daily precipitation, surface water infiltration, surface water runoff, evapotranspiration, and deep percolation (see Figure 3). The deep percolation term given by the watershed model is considered an estimate of the average annual ground water recharge.

The model code used for the Big Bear Lake Watershed model was the Hydrological Simulation Program Fortran (HSPF; EPA, 1997). This program uses measured precipitation and potential evapotranspiration[1] (PET) to estimate surface water runoff, actual evapotranspiration[2] (ET), and

[1] The amount of water that would be lost to the atmosphere through evaporation and uptake by plants (transpiration) under a given climatic condition if there were unlimited soil moisture.

[2] The amount of water that would be lost to the atmosphere through evaporation and uptake by plants (transpiration) under a given climatic and soil moisture condition.

ground water recharge within the watershed. Input data were formatted for the model using the code Generation and Analysis of Model Simulation Scenarios (GenScn).

A watershed model was developed, based on the watershed model developed for GEOSCIENCE (2001), to assess ground water recharge in each of the tributary subareas for the North Shore and Grout Creek Subunits. In addition to refining the tributary subareas of each subunit, input parameters for the model were selected according to the most recent EPA guidelines for estimating hydrology and hydraulic parameters specific to HSPF (EPA, 2000).

### 3.3.1 Conceptual Watershed Model

As any given volume of precipitation falls within a watershed or, in this case, tributary subarea, it is ultimately subject to multiple fates as shown on Figure 3. Interaction of precipitation with the ground surface will generally determine the volume of streamflow within the subarea. Among the processes that actively govern streamflow at the ground surface are initial abstraction, infiltration, and overland flow. Ground water recharge occurs if the amount of infiltration exceeds the capacity of the soil to hold the water.

#### 3.3.1.1 Initial Abstraction

A portion of the precipitation falling on the watershed tributary subarea is intercepted by vegetation and other above ground objects, such as buildings, and is defined as interception. Part of the intercepted precipitation wets and adheres to these objects before returning to the atmosphere through evaporation. This mechanism is called "interception loss".

The water that does reach the ground during precipitation events can follow several pathways that do not necessarily result in ground water recharge. Almost immediately, some of the water is evaporated from the soil surface. Some precipitation is temporarily stored in topographic depressions (i.e. "depression or surface detention storage") where it can slowly infiltrate into the subsurface or evaporate. Some precipitation infiltrates into the shallow subsurface where it is either evaporated back out of the soil zone or is utilized by plants. The effects of vegetation interception, transpiration, evaporation, and depression storage are combined to determine a volume of water that is referred to as "initial abstraction" or "initial loss."

In summary, of the precipitation that reaches the ground surface within any given watershed, a substantial portion is prevented from percolating to the ground water due to:

- Interception by impermeable surfaces (rocks, concrete, etc.) and evaporated,
- Evaporation directly off of the ground surface,
- Evaporation out of the shallow soil zone, and
- Interception and utilization by plants.

Previous evaluations of natural ground water recharge in southern California have resulted in estimates in the range of 3 to 7 percent of precipitation (MWD, 1999). This is also consistent with recharge studies in similar climatic settings in other parts of the southwestern United States (Daniel B. Stevens & Associates, 1996).

#### 3.3.1.2 Infiltration and Interflow

A portion of the precipitation that reaches the ground surface infiltrates into the shallow subsurface. This infiltration is a function of many variables, including (but not limited to) soil permeability, vegetation type and cover, surface slope, precipitation intensity and duration, and the ambient moisture content of the soil. If the supply rate of precipitation is greater than the capacity of the soil to accommodate it, infiltration will occur into the shallow subsurface.

Movement of infiltrating water in the shallow subsurface is known as interflow. Infiltration rate is highly dependent on soil permeability and, if low permeability layers exist above the water table, infiltrating water can temporarily pond in these areas(a condition known as interflow detention storage). Depending on the permeability of the soil and the amount of infiltrating water, some of the water will evaporate back out of the soil and some will percolate to the ground water as recharge.

#### 3.3.1.3 Overland Flow

If the volume of precipitation that reaches the ground surface exceeds the initial abstraction, overland flow occurs and collects to form small rivulets, which eventually lead to streams (known as routing). Because infiltration occurs at the same time as overland flow, the relationship between the two processes must be considered. For example, spatial variations in the infiltration characteristics of the ground cover will allow overland flow in some areas and not others.

#### 3.3.1.4 Ground Water Recharge

If the volume of water in the shallow soil zone exceeds the field capacity (the amount of water that can be held by the soil particles without draining away) and the amount that is evaporated or consumed by plants (ET), it will percolate to the ground water surface as recharge. Depending on the depth to ground water, some of this water may still be subject to ET.

### 3.3.2 Model Input

#### 3.3.2.1 Model Subareas

After subdividing the North Shore and Grout Creek Hydrologic Subunits into tributary subareas, hydrologic parameters (i.e. topographic characteristics, precipitation, and ET) unique to each subarea were then assigned to the model. Watershed model simulations were carried out for each tributary subarea within the respective hydrologic subunits.

### 3.3.2.2 Precipitation

The only inflow term into the watershed model is precipitation because all of the Big Bear Lake Watershed s available water resources are from precipitation. A summary of annual precipitation data from the Big Bear Lake Dam station is provided in Table 1. A precipitation isohyetal map from the San Bernardino County Flood Control District, based on precipitation records collected from Big Bear area weather stations between 1870 and 1970 is shown on Figure 4.

From the isohyetal map, a long-term weighted mean precipitation was assigned to each tributary subarea (see Figure 4). This long-term weighted mean precipitation was the basis for input into the watershed model. However, because the watershed model requires daily precipitation, daily precipitation input values had to be calculated for each tributary subarea. Daily precipitation input was calculated for each tributary subarea as the daily precipitation from the Big Bear Lake Dam Weather Station multiplied by an adjustment factor to account for the decrease in average annual precipitation from the dam eastward (see Figure 4). The adjustment factor is the long-term weighted mean annual precipitation of each tributary subarea divided by the measured mean annual precipitation of the Big Bear Lake Dam Weather Station.

As an example, the long-term weighted mean precipitation for Tributary Subarea A of the Grout Creek Hydrologic Subunit is 33.44 inches per year. The long-term average precipitation for the Big Bear Lake Dam Weather Station is 34.6 inches per year. The adjustment factor for daily precipitation input to Grout Creek Tributary Subarea A of the watershed model is 33.44 divided by 34.6 or 0.97. Thus, the daily precipitation values assigned to this subarea of the model are the daily precipitation values from the Big Bear Lake Dam Weather Station, each multiplied by 0.97.

#### 3.3.2.3 Potential Evapotranspiration

Daily potential evapotranspiration (PET) for the Big Bear Lake area was estimated based on monthly evaporation records from the BBCCSD pan (see Figure 4). Annual evaporation records are summarized in Table 2. Average monthly evaporation, as measured from the BBCCSD pan ranges from 0.16 inches in February to 8.4 inches in July.

#### 3.3.2.4 Other Input Parameters

In addition to measured and calculated input parameters, HSPF requires additional parameters that must be assumed for areas where measured hydrologic data are not available. For the Big Bear area, 18 of the 20 required input parameters were estimated from ranges of values published in United States Environmental Protection Agency (EPA) guidelines because measured data for those parameters were not available (EPA, 2000). The EPA guidelines are based on a database of measured data for each parameter collected from sites across the continental United States. Thus, the published values are not specific to any particular area.

Published parameter values from the EPA guidelines include a typical maximum and minimum range and a possible maximum and minimum range (see Table 3). Statistically, it is more likely that any given parameter for a specific area of the United States would fall into the typical range of values. However, the possible range is included to consider areas where non-normal conditions could exist. For the Grout Creek and North Shore watershed model, the average of the typical and possible ranges of input parameters provided the range of input values used in the model.

### 3.3.3 Model Output

#### 3.3.3.1 Surface Runoff

The precipitation that reaches the ground surface (after interception) is separated into infiltration, interflow storage, surface detention storage, or runoff. The amount of water allotted to infiltration and interflow storage is a function of the infiltration characteristics of the soils within the model subarea and the slope of the land surface.

When precipitation amounts exceeded soil infiltration capacity, the balance of available water was separated into surface runoff, which was estimated using the Chezy-Manning equation (Crawford and Linsley, 1966) and an empirical expression that relates runoff depth to depression storage. The rate of surface runoff is determined by the following equation:

$$R = (t)(r)(D_s)(1+0.6(D_s/D_{se})^3)^{1.67}$$

where:

$R =$ Surface Runoff, [inches/t]

$t =$ Time Interval, [hr/interval]

$r =$ Routing Variable, [unitless]

$D_s =$ Mean Surface Detention Storage Over the Time Interval, [inches]

$D_{se} =$ Equilibrium Surface Detention Storage (inches) for Current Supply Rate

The routing variable is given by the following equation:

$$r = 1{,}020\sqrt{S_{LS}}/(n)(l)$$

where:

$S_{LS}$ = Slope of the Runoff Surface, [ft/ft]

n = Manning Friction Coefficient, [unitless]

l = Length of the Runoff Surface, [ft]

#### 3.3.3.2 Evapotranspiration

Actual ET calculated by the watershed model is represented as a function of the potential ET (PET) described in Section 2.3.2.3 and the sum of ET from surface water, interception storage, the upper soil zone, shallow ground water, and the lower soil zone (i.e. vadose zone). Total PET demand is met from these sources, starting with surface water and proceeding through the other sources in the order listed. For example, the surface water in the model (not including interception storage) will be used up until the PET demand is met. Remaining PET will then be satisfied from interception storage. If interception storage does not meet the PET demand, then water from the upper soil zone will be utilized, etc. The actual ET calculated by the model is the sum of the ET sources used to fulfill the PET demand.

#### 3.3.3.3 Ground Water Recharge

The watershed model calculates ground water recharge (deep subsurface percolation) by subtracting runoff and actual ET from the total precipitation applied to the model area.

# 4.0 NORTH SHORE HYDROLOGIC SUBUNIT

## 4.1 Location

The North Shore Hydrologic Subunit is located on the northern side of the Big Bear Lake Watershed and is defined by the drainage catchment south of the ridge associated with Bertha Peak (see Figure 5). The total surface area of the subunit is approximately 3,560 acres. The highest elevation within the subunit is the top of Bertha Peak at an elevation of approximately 8,200 ft amsl. Surface water is drained from the higher elevations to Big Bear Lake via a number of small drainages, including Polique and Minnelusa Canyons.

## 4.2 Geohydrology

### 4.2.1 Geology

The predominant rock type within the North Shore Subunit is Paleozoic carbonate rocks of the Furnace Group (FCT), which are exposed at the surface in the higher elevations of the drainage catchment. Scattered outcrops of Mesozoic granitic rock have also been mapped throughout the subunit. Younger alluvium has been deposited in the drainage channels and along the margins of Big Bear Lake. The alluvium is greater than 400 ft thick in the western portion of the subunit (Mooncamp Area) and in the central portion of the subunit (RV Park Well No. 2). In the eastern portion of the subunit, the alluvium is approximately 400 ft thick at Division Well Nos. 6 and 7. Older alluvium is exposed as alluvial fans between the younger alluvium in the lower elevations and the bedrock at the higher elevations.

### 4.2.2 Ground Water

Ground water in the North Shore Hydrologic Subunit generally occurs in the unconsolidated alluvial deposits on the lower slopes of the surrounding mountains and in the fractures and weathered portions of the bedrock. Ground water in the alluvium occurs at depths ranging from approximately 5 ft in the western portions of the subunit and near the RV Park wells to approximately 50 ft near Division Well Nos. 6 and 7.

Ground water flows by gravity drainage from areas of high elevation (the mountain slopes) into areas of low elevation, ultimately collecting in the sediments beneath Big Bear Lake. Ground water recharge likely occurs as deep percolation of runoff through the younger alluvium and fractures in the bedrock during periods of prolonged precipitation.

The primary sources of ground water discharge from the North Shore Subunit are underflow and ground water pumping from wells within the subunit. The BBDWP currently operates four vertical production wells within the North Shore Subunit (RV Park Well Nos. 1 and 2 and Division Well Nos. 6 and 7). Combined average annual ground water production from BBDWP wells between 1993 and 2002 is 282 acre-ft/yr (see Table 4). An average of approximately 14 acre-ft/yr of the total BBDWP production from this subunit is from the RV Park wells with the remainder from Division Well Nos. 6 and 7 (see Figure 5). Pumping data for the 20 private wells in the subunit were not available. However, assuming that they are domestic sources and that an average single family home uses approximately 200 gpd/yr, it is estimated that production from these wells is approximately 4.5 acre-ft/yr.

Ground water levels in the central portion of the North Shore Hydrologic Subunit, as measured in RV Park Well No. 1, have declined approximately 20 ft between 1996 and 2002 (see Figure 6). The ground water level in this well is relatively stable, however, with most of the decline occurring after year 2000, a period of relatively dry climatic conditions. Ground water levels in Division Well No. 6, located in the eastern portion of the subunit, have declined approximately 80 ft between 1992 and 2003 (see Figure 6). Recent ground water level declines in the eastern portion of the subunit can also be correlated with dry climatic conditions although the greater degree of decline is also a reflection of higher ground water production in the area.

### 4.3 Estimates of Average Annual Ground Water Recharge

Average annual ground water recharge in the North Shore Hydrologic Subunit was reevaluated in the context of the six tributary subareas described in Section 2.1 (see Figure 2). Use of the underflow method was not possible because static ground water level data necessary to construct flow nets in the individual tributary subareas, were not available. Accordingly, estimates of average annual ground water recharge were assigned to each tributary subarea using the watershed model only. The construction and monitoring of future monitoring wells and pumping tests in production wells (new or existing) in the tributary subareas would enable the generation of underflow estimates. In addition, the ground water recharge estimates from the watershed model can be refined as additional data, as described in Section 2.0, are collected.

The watershed model described in Section 2.3 was used to assess the average annual ground water recharge specific to each tributary subarea of the North Shore Hydrologic Subunit. Required input parameters for the watershed model for which no measured data were available were obtained from the EPA database of hydrologic parameters (EPA, 2000) as described in Section 2.3.2.4 and summarized in Table 3. The resulting ranges of annual recharge for each of the tributary subareas are summarized in Table 5 and shown on Figure 5.

Based on the watershed modeling results, the estimates of average annual ground water recharge for the North Shore Hydrologic Subunit range from approximately 150 to 430 acre-ft/yr with a midpoint of approximately 290 acre-ft/yr. This range of recharge is approximately 2 to 7 percent of average annual precipitation for the subunit, which is within the range of accepted recharge estimates for other ground water basins in southern California (3 to 7 percent; Metropolitan Water District of Southern California (MWD), 1999). The midpoint of the range is approximately 4.5 percent of precipitation for the subunit. For comparison of the modeling results, ground water recharge as 3, 5, and 7 percent infiltration of the weighted average of annual precipitation for each of the tributary subareas are summarized in Table 6.

The midpoint of the revised range of average annual ground water recharge estimates for the North Shore Hydrologic Subunit is approximately 30 acre-ft/yr higher than the maximum perennial yield reported in GEOSCIENCE (2001), which was based primarily on ground water level trends in production wells in two isolated portions of the hydrologic subunit. The watershed model results for this study are lower than the watershed model results reported in GEOSCIENCE (2001) as a result of the use of the EPA parameter input database for this study.

Estimates of average annual ground water recharge for the six tributary subareas range from 27 acre-ft/yr (Subarea E) to 73 acre-ft/yr (Subarea B; see Figure 5). These ground water recharge estimates represent the average of the watershed model output range (see also Figure 5), which is based on the average of typical and possible input values. These data suggest that the RV Park wells are producing ground water at a rate (approximately 14 acre-ft/yr) that is well within their subarea s average annual ground water recharge. Combined average annual ground water production from Division Well Nos. 6 and 7 is exceeding that subarea s average annual ground water recharge. However, it is important to note that these wells are in the alluvial portion of the subarea, which is in hydraulic continuity with the alluvial portions of the adjacent hydrologic subunit (i.e. the Division Subunit to the south). Accordingly, production from these wells should be evaluated in the context of the ground water basin in this area and not the watershed tributary to the wells.

### 4.4 Maximum Perennial Yield

As stated earlier, the maximum perennial yield is the maximum quantity of ground water perennially available if all possible methods and sources are developed for recharging the basin. This quantity depends on the amount of water economically, legally, and politically available to the BBDWP. Given this definition, the maximum perennial yield of the North Shore Hydrologic

Subunit is within the range of average annual ground water recharge specified by the watershed model but is more likely to be in the lower end of the range than the upper end due to the impracticality of developing all of the recharge water. For initial planning purposes, it is recommended that the midpoint recharge estimates for each tributary subarea (see Figure 5) is used as the maximum perennial yield for that subarea until additional data can be collected (i.e. a ground water level history). It should be emphasized that as ground water production is initiated in each subarea, it will be very important to monitor ground water levels in dedicated non-pumping monitoring wells (i.e. key wells ) located in each tributary subarea from which ground water is extracted. Future management of the ground water resources in each tributary subarea should rely more on established ground water level thresholds than the perennial yield estimates.

# 5.0 GROUT CREEK HYDROLOGIC UNIT

## 5.1 Location of Grout Creek Hydrologic Subunit

The Grout Creek Hydrologic Subunit is located on the northwest end of the Big Bear Lake Watershed and is defined by the drainage catchment between Delamar Mountain and Little Bear Peak to the north and Gray s Peak to the south (see Figure 7). The total surface area of the subunit is approximately 4,184 acres. The highest elevation within the subunit is the top of Delamar Mountain at an elevation of approximately 8,400 ft amsl. The town of Fawnskin is located at the lowest portion of the subunit in the vicinity of Big Bear Lake (elevation of 6,744 ft amsl). The primary surface water drainage feature of the catchment is Grout Creek.

## 5.2 Geohydrology

### 5.2.1 Geology

The predominant rock type within the Grout Creek subunit is Mesozoic granitic rock. Younger alluvium has been deposited in the drainage channels and overlies older alluvium, which fills in the remainder of the alluviated portions of the catchment. The thickness of the alluvium is as much as 180 ft at Well 13B01 in the eastern portion of the subunit, and becomes thinner to the west (approximately 100 ft thick).

### 5.2.2 Ground Water

Ground water within the Grout Creek subunit occurs in both the bedrock and alluvium. The Cedar Dell slant wells are drilled into the Mesozoic granitic rock and typically produce about 20 gallons per minute, collectively. Ground water in the alluvium occurs at depths ranging from approximately 20 to 90 ft and flows to the south toward Grout Bay (Big Bear Lake) at a gradient of 0.024 to 0.043 ft/ft (see inset on Figure 7). Pumping test and lithologic data from the Barbara Lee Lane Well and specific capacity data from Wells 12P01, 13C01, and Northshore Well Nos. 1, 2, and 3 were used to estimate aquifer transmissivity. Estimates range from 700 to 1,900 gpd/ft.

Ground water recharge likely occurs within the Grout Creek streambed during periods of extended runoff, near the contact between the bedrock and alluvium and, to a lesser extent, as percolation of precipitation directly on the alluvium. Ground water recharge also occurs through fractures in the bedrock formations.

The primary sources of ground water discharge from the Grout Creek subunit are underflow and ground water pumping from wells within the subunit. BBDWP currently operates two vertical production wells, two slant wells in bedrock, and one spring within the Grout Creek subunit. Average annual ground water production from BBDWP wells within the subunit from 1989 to 2002 has been approximately 134 acre-ft/yr (see Table 7). With the exception of pumping from Barbara Lee Lane Well No. 1, all of the municipal ground water production in the Grout Creek Hydrologic Subunit is from Tributary Subarea C (see Figure 7). Pumping data for the 29 private wells in the subunit were not available. However, assuming that they are domestic sources and that an average single family home uses about 200 gpd/yr, it is estimated that production from these wells is approximately 6.5 acre-ft/yr.

### 5.2.3 Ground Water Levels

Ground water level elevations in North Shore Well Nos. 1 and 3, both located at the discharge end of Tributary Subarea C, have been relatively stable between 1995 and 2003, with seasonal fluctuations and a minor decline during the relatively dry climatic cycle from 1999 to present (see Figure 8).

## 5.3 Estimates of Average Annual Ground Water Recharge

The average annual ground water recharge of the Grout Creek subunit was estimated using the underflow method and the watershed model.

### 5.3.1 Ground Water Underflow Calculation

The amount of ground water underflow beneath the Grout Creek subunit was estimated through the flow net shown on Figure 7. This flow net was used in the most recent Maximum Perennial Yield analysis for the Big Bear Lake area (GEOSCIENCE, 2001) and indicated an average annual ground water recharge estimate of approximately 200 acre-ft/yr. It should be noted, however, that the underflow calculation only accounts for outflow in the alluvial aquifer and does not account for outflow through the bedrock in the subunit. It is assumed that some outflow occurs within the bedrock aquifer, which is one reason why the underflow estimate for the Grout Creek Subunit is lower than the perennial yield estimate from the watershed model (described below).

Previous perennial yield estimates (GEOSCIENCE, 2001) have been based on the assumption that production of water from the bedrock aquifer is not as economically feasible as production of water from the alluvial aquifer. For the purposes of this study, however, the bedrock aquifer in the Grout Creek and North Shore Subunits is considered a viable ground water production source and is included in the total perennial yield estimate for the respective subunits.

### 5.3.2 Watershed Model

The watershed model described in Section 2.3 was used to assess the average annual ground water recharge specific to each tributary subarea of the Grout Creek Hydrologic Subunit.

Assumed input parameters for the watershed model are based on the average of EPA s suggested parameter ranges, which are summarized in Table 3. The resulting ranges of annual recharge for each of the tributary subareas are summarized in Table 8 and shown on Figure 9.

Based on the watershed modeling results, the average annual ground water recharge for the Grout Creek Hydrologic Subunit (Subareas A through D) is estimated to range from approximately 260 to 840 acre-ft/yr with a midpoint of approximately 550 acre-ft/yr. This range of recharge is approximately 2 to 8 percent of average annual precipitation for the subunit. The midpoint of the range is approximately 5 percent of precipitation for the subunit. For comparison of the modeling results, ground water recharge as 3, 5, and 7 percent infiltration of the weighted average of annual precipitation for each of the tributary subareas are summarized in Table 9.

The relative disparity between the average annual recharge estimates obtained from the underflow analysis and watershed model is partly due to the estimated nature of the input parameters used in each analysis. In the case of the underflow analysis, the transmissivity parameter is estimated based on review of lithologic logs and pumping tests in wells within the Big Bear area that are perforated in similar aquifer materials. More representative values can be obtained via formal aquifer pumping tests using the wells in the subunit. For the watershed model, 18 of the 20 required input parameters are estimated from the EPA s database, which is not specific to the mountains of southern California. Additionally, the underflow analysis does not account for all of the recharge within the bedrock. As data are collected in the future, the range of recharge will become less.

The midpoint of the revised average annual ground water recharge for Subareas A through D of the Grout Creek Hydrologic Subunit (549 acre-ft/yr) is approximately 120 acre-ft/yr lower than the average annual ground water recharge from the watershed model reported in GEOSCIENCE (2001) (670 acre-ft/yr). As stated previously, the revised estimate is a result of the use of the EPA parameter input database for this study.

Estimates of average annual ground water recharge for the four tributary subareas range from 66 acre-ft/yr (Subarea D) to 217 acre-ft/yr (Subarea C; see Figure 9). These average annual recharge values represent the average of the watershed model output range (see also Figure 9), which is based on the average of typical and possible input values. These data suggest that average annual ground water production from the Grout Creek Hydrologic Subunit (approximately 134 acre-ft/yr), which occurs almost entirely from Tributary Subarea C, is within the average annual recharge for both the tributary subarea and the hydrologic subunit.

### 5.4 Maximum Perennial Yield

The maximum perennial yield of the Grout Creek Hydrologic Subunit is within the range of average annual ground water recharge specified by the watershed model but is more likely to be in the lower end of the range than the upper end. As mentioned previously, by definition, maximum perennial yield is the amount of water that can be developed economically, legally and politically. In consideration of this, Subareas A and B of the Grout Creek Subunit are remote and are located on land under the jurisdiction of the United States Forest Service (USFS). There is no established distribution system in Subareas A and B of the Grout Creek Subunit. Furthermore, access to the area would likely require a lengthy negotiation process with the USFS. Given these factors, developing ground water resources in these subareas is not currently practical.

At this time, it is recommended to use the sum of the midpoint recharge estimates for tributary Subareas C and D (217 acre-ft plus 66 acre-ft; see Figure 9) as the maximum perennial yield for the Grout Creek Subunit (total of 283 acre-ft/yr). It should be emphasized that as ground water production is initiated in each subarea, it will be very important to monitor ground water levels in dedicated non-pumping monitoring wells (i.e. key wells ) located in each tributary subarea from which ground water is extracted. As was recommended for the North Shore Hydrologic Subunit, future management of the ground water resources in each tributary subarea should rely more on established ground water level thresholds than the perennial yield estimates.

## 6.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the analyses presented in this report, the following have been concluded regarding the maximum perennial yield of the North Shore Hydrologic Subunit:

- The North Shore Hydrologic Subunit can be conveniently subdivided into six tributary subareas (A through F) based on surface water drainage divides;

- The revised range of average annual ground water recharge for the North Shore Hydrologic Subunit as a whole is approximately 150 to 430 acre-ft/yr with a midpoint of approximately 290 acre-ft/yr. The midpoint of the range is approximately 4.5 percent of precipitation for the subunit, which is within the range of accepted recharge estimates for other ground water basins in southern California (3 to 7 percent).

- The midpoint of the average annual ground water recharge estimate (290 acre-ft/yr) is considered a good estimate of maximum perennial yield for the North Shore Hydrologic Subunit, given the available data. However, additional ground water monitoring and geohydrologic data collection are required in each individual subarea to manage the ground water resources in the area as it is developed in the future;

- The revised perennial yield is slightly higher than the previous perennial yield value of 260 acre-ft/yr from the GEOSCIENCE, 2001 report, primarily as a result of the use of an updated EPA input parameter list for the watershed model and the consideration of the bedrock aquifer as a viable source of ground water supply;

- The total ground water recharge for the North Shore Subunit was apportioned to the individual tributary subareas as shown on Figure 5.

- Combined average annual ground water production from Division Well Nos. 6 and 7 is exceeding that subarea s average annual ground water recharge. However, these wells are in the alluvial portion of the subarea, which is in hydraulic continuity with the alluvial portions of the adjacent hydrologic subunit (i.e. the Division Subunit to the south). Accordingly, production from these wells should be evaluated in the context of the ground water basin in this area and not the watershed tributary to the wells.

For the Grout Creek Hydrologic Subunit, the following is concluded:

- The Grout Creek Hydrologic Subunit can be conveniently subdivided into four tributary subareas (A through D) based on surface water drainage divides;

- The revised range of average annual recharge for the Grout Creek Hydrologic Subunit as a whole is approximately 260 to 840 acre-ft/yr with a midpoint of approximately 550 acre-ft/yr (Subareas A through D). The midpoint of the range is approximately 5 percent of precipitation for the subunit, which is within the range of accepted recharge estimates for other ground water basins in southern California (3 to 7 percent)

- Ground water resources in Subareas A and B of the Grout Creek Subunit would be difficult to develop because they are remote and are located on land under the jurisdiction of the USFS;

- Due to the cost and political limitations associated with ground water development in Subareas A and B, it is currently recommended to use the sum of the midpoint recharge estimates for tributary Subareas C and D (283 acre-ft/yr) as the maximum perennial yield for the Grout Creek Subunit;

- The revised perennial yield (283 acre-ft/year) is higher than the previous perennial yield value of 200 acre-ft/yr from the GEOSCIENCE, 2001 report, primarily as a result of the use of an updated EPA input parameter list for the watershed model and the consideration of the bedrock aquifer as a viable source of ground water supply;

- The total average annual ground water recharge for the Grout Creek Subunit was apportioned to the individual tributary subareas as shown on Figure 9.

Given the possible range of recharge for the North Shore and Grout Creek Hydrologic Subunits, and correspondingly the range of recharge for the individual tributary subareas within each subunit, it is recommended that development planning for tributary subareas be initially based on the maximum perennial yield estimates as described above. However, as ground water production is initiated in each tributary subarea, it will be very important to monitor ground water levels in dedicated non-pumping monitoring wells located in each tributary subarea from which ground water is extracted. The maximum perennial yield is based on long-term precipitation records. However, short-term periods (5 to 10 years) of relatively low precipitation have been observed throughout the period of record. These short-term periods of low precipitation are anticipated to have a significant impact on the ground water levels in the North Shore and Grout Creek Hydrologic Subunits because the storage capacity of the ground water reservoir is relatively small (shallow alluvium underlain by granitic bedrock). For this reason, future ground water production, and development, in each tributary subunit should rely more on established ground water level thresholds than the perennial yield estimates.

Another aspect of maximum perennial yield to consider is the reduction in perennial yield from development. As buildings and roads are built over soil that once was available to receive recharge from precipitation, the amount of surface water runoff will increase and the amount of ground water recharge will decrease. Any proposed future developments should address this issue.

As additional monitoring features (e.g. monitoring wells) are constructed and additional data become available, the perennial yield estimates will be refined. Hydrologic data that, if measured in the Grout Creek and North Shore areas, would have the greatest impact on the perennial yield values for the subunits and tributary subareas (and the Big Bear Lake Watershed as a whole) would include:

- Ground water monitoring wells in each of the tributary subareas,

- Additional information from private wells in each of the tributary subareas,

- Stream flow discharge (as would be measured from stream gages) for the major tributaries in the Grout Creek and North Shore subunits;

- Additional weather stations in the Grout Creek and North Shore subunits that would be equipped with instrumentation to measure:
  - Precipitation (including snow accumulation),
  - Ambient air temperature,
  - Vertical and horizontal wind speed and direction,
  - Relative humidity,
  - Barometric pressure,
  - Water vapor density,
  - Solar radiation,
  - Soil temperature,
  - Soil heat flux, and
  - Soil moisture content;

- Evaporation pans at each weather station location; and

- Pumping tests in selected wells to obtain aquifer parameters.

Of the monitoring features to be developed, first priority should be given to the construction of monitoring wells and the development of a reliable ground water level baseline. From this, ground water level thresholds should be established within which to manage ground water production. As mentioned previously, future ground water production, and development, in each tributary subunit should rely more on established ground water level thresholds than the perennial yield estimates. Given this, the relative cost of establishing the other monitoring features necessary to refine the maximum perennial yield estimates should be weighed against the relative benefit of refining the maximum perennial yield.

## 7.0 REFERENCES

Brown, G.A. and Fox, R., 1978. Hydrogeologic Studies, Big Bear Lake - Baldwin Lake Area. Prepared for the Big Bear City Community Services District and Southern California Water Company.

California Division of Mines and Geology, R. H. Jahns ed., 1954. Geology of Southern California. Bulletin 170, Volume 1. September 1954.

Daniel B. Stevens & Associates, 1996. Estimation of Infiltration and Recharge for Environmental Site Assessment; in *Natural Recharge of Groundwater Symposium*, sponsored by the Arizona Hydrological Society, Arizona Dept. of Water Resources, Salt River Project, U.S. Water Conservation Laboratory, and U.S. Geological Survey; June 2, 2000.

Dibblee, T.W. Jr., 1964. Geologic Map of the Lucerne Valley Quadrangle, San Bernardino, California. Map I-426, USGS.

Dibblee, T.W. Jr., 1964. Geological Map of the San Gorgonio Mountain Quadrangle, San Bernardino and Riverside Counties, California. Map I-431, USGS.

Dowdy, D.R. ad O Donnel, T., 1965. Mathematical Models of Catchment Behavior. ASCE Journal of Hydraulics Division, Vol. 91.

Donigan, A.S. Jr., Imhoff, J.C., and Kittle, J.L. Jr. An Interactive Database of HSPF Model Parameters, Version 1.0, United States Environmental Protection Agency, April 1999.

EPA, 2000. Basins Technical Note 6; Estimating Hydrology and Hydraulic Parameters for HSPF, United States Environmental Protection Agency, EPA-823-ROO-012, July 2000.

GEOSCIENCE Support Services, Inc., 1992. Draft Re-evaluation of Maximum Perennial Yield Big Bear Ground Water Basins San Bernardino County, California. Prepared For City Of Big Bear Lake, Department Of Water And Power. June 15, 1992.

GEOSCIENCE Support Services, Inc., 1999. Re-Evaluation of the Maximum Perennial Yield in the Baldwin Lake Watershed. Prepared for Big Bear City Community Services District. July 13, 1999.

GEOSCIENCE Support Services, Inc., 2001. Geohydrologic Investigation of the Moon Camp Area Big Bear Valley, California. Prepared for City Of Big Bear Lake Department Of Water And Power. July 13, 2000.

GEOSCIENCE Support Services, Inc., 2001. Re-Evaluation of the Maximum Perennial Yield Big Bear Lake Watershed and a Portion of Baldwin Lake Watershed. Prepared for City of Big Bear Lake Department of Water And Power. August 24, 2001.

Glenn A. Brown and Associates, 1974. Geohydrology of Big Bear Lake and Baldwin Lake Drainage Areas. Presented as Appendix N in Rowe and Bueermann (1985).

Law Environmental, 1988. Completion Report - Construction and Evaluation of Wells FP-2 and FP-3 Moon Camp Subdivision, Big Bear Lake, California. Prepared for Forest Properties, Big Bear Lake, California.

LeRoy Crandall and Associates, 1987a. Re-Evaluation of Sustained Ground Water Yields, Big Bear Lake Watershed, San Bernardino County, California. Prepared for the City of Big Bear Lake.

Maidment, D.R., ed., 1993. Handbook of Hydrology. McGraw-Hill, Inc., San Francisco.

Metropolitan Water District of Southern California, 1999. Memorandum, Fenner Basin Precipitation and Recoverable Water Estimates. Prepared by Tom Freeman of the Technical Review Panel for the Cadiz Groundwater Storage and Dry-Year Supply Project.

Martin, T., 1992. Summary of Geology, Geography, Flora and Fauna Around Big Bear Valley. Valley Voice (Big Bear City Newspaper), December 1992.

Miller, Fred K., 1987. Reverse-Fault System Bounding the North Side of the San Bernardino Mountains, in Recent Reverse Faulting in the Transverse Ranges, California. USGS Professional Paper 1339. pp. 83 - 95.

Roscoe Moss Co., 1990. Handbook of Ground Water Development. John Wiley & Sons.

Sadler, P.M., 1982. Geology of the San Bernardino Mountains. California Division of Mines and Geology Open File Report 82-18LA.

Santa Ana Watershed Project Authority, 1998. Water Resources Plan. June 1998.

Thornthwaite, C.W., 1948. An Approach Toward a Rational Classification of Climate. Geog. Rev., v. 38, p. 55-94.

Todd, D.K., 1980. Groundwater Hydrology. Second Edition, John Wiley & Sons.

United States Soil Conservation Service, 1957. Use of Storm and Watershed Characteristics in Synthetic Hydrograph Analysis and Application. U.S. Department of Agriculture, Washington, D.C.

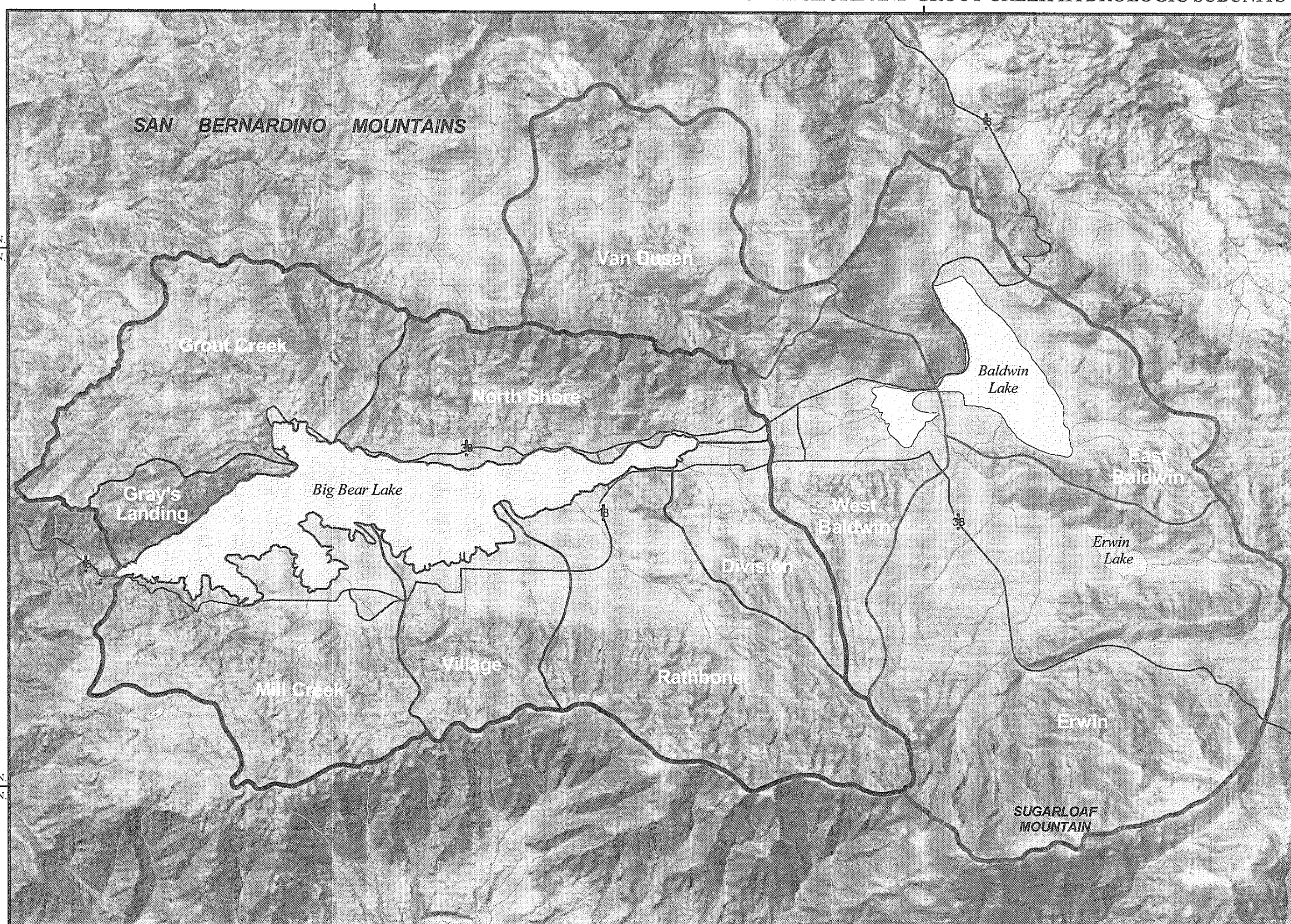
Williamson and Schmid, 1986. County of San Bernardino Hydrology Manual. County of San Bernardino.

# FIGURES

CITY OF BIG BEAR LAKE
DEPARTMENT OF WATER AND POWER

**FOCUSED GEOHYDROLOGIC EVALUATION OF THE MAXIMUM PERENNIAL YIELD OF THE NORTH SHORE AND GROUT CREEK HYDROLOGIC SUBUNITS**

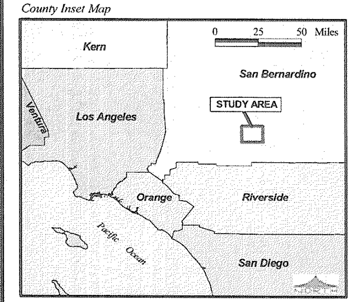
## LOCATION OF BIG BEAR VALLEY




EXPLANATION

- Big Bear Lake Watershed Boundary with Hydrologic Subunits
- Baldwin Lake Watershed Boundary with Hydrologic Subunits
- Road
- Surface Water
- Playa Lake
- Creek or River

County Inset Map




Prepared by: DWB

2-DEC-03

Map Projection:
UTM Zone 11, NAD27
Central Meridian: -117 degrees

GEOSCIENCE
GEOSCIENCE Support Services, Inc.
P.O. Box 220, Claremont, CA 91711
Tel: (909) 920-0707 Fax: (909) 920-0403
E-mail: email@geoscience-water.com

**Figure 1**

GIS_proj\bbldwp_north_shore_per_yield_12-03\bbldwp_northshore_12-03_figs.apr