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Big Sky County Water and Sewer District No. 363

SOURCE WATER DELINEATION AND ASSESSMENT REPORT

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September 2002

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WESTERN
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SERVICES

BIG SKY COUNTY WATER AND SEWER DISTRICT NO. 363
SOURCE WATER DELINEATION AND ASSESSMENT REPORT

MEADOW VILLAGE (PWS No. 2384)
MOUNTAIN VILLAGE (PWS No. 2385)
ASPEN GROVES SUBDIVISION (PWS No. 4064)
LONE MOOSE MEADOWS CONDOMINIUMS (EQ No. 98-1456)

Prepared for:

Big Sky County Water and Sewer District No. 363
Big Sky, Montana

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September 13, 2002

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1 INTRODUCTION

Source Water Protection Planning is intended to reduce the risk of contamination to water sources serving public water systems. The U.S. Environmental Protection Agency and the U.S. states have each developed Source Water Protection Programs for this purpose. These programs are developed in accordance with the 1996 Safe Drinking Water Act Amendments.

The first phase of Source Water Protection Planning involves the preparation of a Source Water Delineation and Assessment Report (SWDAR). The SWDAR provides technical information that serves as a basis for planning activities to reduce the risk of source water contamination. Four water systems, owned and operated by the Big Sky County Water and Sewer District No. 363 (District), are specifically addressed in this SWDAR, including: Meadow Village (No. 2384), Mountain Village (No. 2385), Aspen Groves Subdivision (No. 4064). In addition, the District recently annexed the Lone Moose Meadows Condominiums (EQ No. 98-1456) development into the water and sewer district and will, after the owner completes a final system punch list, own and operate this water system as well. Each of these water systems is a regulated community water system in the state of Montana[1].

This SWDAR has been prepared to follow the state of Montana format for SWDARs (DEQ 1999) and has undergone state review and approval. Each SWDAR must include the following:

- Background information describing the community, its geography and climate, and the public works facilities;

- Hydrogeological analysis to map recharge areas to the water supply sources. There are several sub-areas mapped for each water supply source;

- Inventory of potential contaminant sources that could possibly impact water quality because they exist within the recharge areas; and

- Assessment of the relative risk of water quality impacts for the most important, or largest, potential sources of contamination.

This SWDAR also includes recommendations to begin protection of the District's water sources. One of the recommendations is to prepare a Source Water Protection Plan (SWPP). Using the SWDAR as a technical basis, the SWPP determines specific activities that can be implemented to maintain or improve drinking water quality. The SWPP is a document prepared with the assistance of an Advisory Committee representing public and private interests in the local area. By implementation of an SWPP, the District will begin to mitigate the risk of source water contamination, addressing both short- and long-term concerns.

This SWDAR was prepared by a consultant with support from District staff. The state of Montana funded over 60% of the project, and the District gratefully acknowledges this financial support[2]. State of

[1] A community water system is a type of public water system with greater than 15 connections, or which serves 25 or more year-round residents.

[2] The state of Montana provided funding to prepare SWDARs for five water systems including: Meadow Village, Mountain Village, Aspen Grove, Lone Mountain Ranch, and Lone Moose Meadows Condominiums. The SWDAR for Lone Mountain Ranch was prepared in a separate report. However, this water system is also shown on selected figures of this SWDAR.

Montana staff from the Source Water Protection Program also provided valuable review comments on the project report. For further information on Source Water Protection Planning by the District, please direct questions to:

SWDAR Primary Contacts:

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About This Report

This report was prepared using existing information obtained from a variety of sources. A diligent effort was made to properly use and assign these data in the report. Readers should be aware, however, that some of this information was poorly documented and there could be inadvertent errors in its use.

1.1 Community

Big Sky, Montana is a resort community located in Gallatin County about 40-miles south of Bozeman, Montana[3]. Figure 1-1 shows a general map of the area. The main transportation route to Big Sky consists of vehicle travel on U.S. Highway 191 south from Bozeman along the scenic West Fork Gallatin River. Gallatin Field located 40-miles north in Belgrade, Montana is the nearest commercial airport.

Development of the Big Sky area began in the 1970s and has continued to the present day. Big Sky has one of the state's highest population growth rates. The local population is estimated at 4,500, and the annual growth rate during the late 1990s ranged from 4% to 7%. Tourism and related services is the primary industry of the area. Most year-round residents are employed directly in the tourism industry or work at a service that supports tourism. Property development and construction is also a common employer of the area. Many of the residents are also tourists who own vacation properties. Some may spend little more than a few weeks a year in the area.

The Big Sky alpine ski area, Lone Mountain Ranch Nordic ski area, and the Meadow Village area golf course are the primary draws to the area. The Yellowstone Club is a newer development located to the southwest of Meadow Village and also provides alpine skiing and golf facilities. The West Fork Gallatin River, the Lee Metcalf Wilderness Area (Spanish Peaks), and the Madison Range provide a variety of outdoor recreation opportunities. The Big Sky alpine ski area between 1995 and 1999 sold more than 290,000 lift tickets, or passes, each year. During 2000, approximately $19 million was spent on lodging alone.

Water and sewer facilities are provided by a mixture of public and private systems. The District operates the largest and most sophisticated of the public water and sewer systems serving the area. There are a few homes served by individual well and septic systems within the District. A few commercial establishments operate small public systems. Domestic sewage is the largest waste generated in the area,

[3] The Madison – Gallatin County line occurs about 1-mile east of Mountain Village. Mountain Village is located in Madison County whereas the Meadow Village and Aspen Grove water systems are located in Gallatin County.

and its handling has required creativity beyond typical methods. The District discharges a highly treated effluent for irrigation of the Meadow Village area golf course (this effluent will also be used at the Yellowstone Club in the future). The effluent is actually a reclaimed wastewater with substantially more treatment than conventional wastewater effluents

1.2 Geography and Climate

The Big Sky area terrain varies from high mountain valley to alpine mountains. The entire area is located within the upper headwaters of the West Fork Gallatin River of the Missouri River. The Meadow Village area is a high valley at an average elevation of about 6,200 feet. The middle- and south-forks of the West Fork Gallatin River meet in the Meadow Village area, which is relatively flat to rolling terrain for about 3 to 4 square miles. Traveling toward Mountain Village along the middle fork, the valley narrows and steep mountain hillside extends to the stream channel. Mountain Village is located at an elevation of about 7,500 ft on a small broad shoulder of Lone Mountain near to a mountain pass. Lone Mountain towers above Mountain Village with a summit elevation of 11,150 ft.

Climate data for the area indicate average moisture, cold winters and cool summers. Two climate data stations shown on Figure 1-2 were used to obtain data for the Big Sky area. The Big Sky 3S station is representative of the Meadow Village area (operated by NOAA). It is located to the south but at similar elevation. The Lone Mountain SNOTEL station is located on Lone Mountain above Mountain Village at an elevation of 8,800 ft (operated by U.S. NRCS). It is a more extreme location than Mountain Village, being more indicative of conditions on Lone Mountain. The climate data obtained from these stations are summarized in Table 1-1 and precipitation data are plotted on Figure 1-3. Based on these data it can be inferred that Lone Mountain receives about 100% more precipitation than Meadow Village. Lone Mountain experiences a precipitation high from December through June. In contrast, the Meadow Village area is much drier during the winter months, with peak precipitation occurring during a two-month period from May through June.

TABLE 1-1
MONTHLY CLIMATE DATA

	Precipitation (in)			Big Sky 3S Temperature (F)		Big Sky 3S Snow Fall	
Month	Lone Mtn SNOTEL	Big Sky 3S	Average	Average Maximum	Average Minimum	Total (in)	Average Depth (in)
Jan	4.0	1.5	2.6	30.9	7.1	38.2	25
Feb	4.0	1.08	2.5	35.5	8.0	18.0	28
Mar	3.8	1.19	2.5	43.2	15.6	19.9	27
Apr	3.6	1.19	2.4	51.6	23.0	5.6	5
May	4.1	2.81	3.5	62.1	30.0	3.2	0
Jun	3.6	2.58	3.1	69.6	35.9	0.2	0
Jul	2.0	1.69	1.8	76.9	39.8	0.3	0
Aug	1.8	1.80	1.8	78.0	38.4	0.0	0
Sep	1.6	1.62	1.6	68.8	31.9	0.2	0
Oct	2.4	1.24	1.8	56.2	23.3	3.6	0
Nov	2.8	1.43	2.1	38.6	13.6	15.7	2
Dec	3.9	1.31	2.6	29.1	5.6	34.1	15
Total or Average	37.6	19.44	28.5	53.4	22.7	139.0	8.5

1.3 Public Water Supply

General information pertaining to the Meadow Village, Mountain Village, Aspen Groves, and Lone Moose water systems is provided below. Detailed maps of the water and sewer facilities for the service areas are provided in Appendix A. The well log for each of the wells included in this SWDAR is also provided in Appendix B.

1.3.1 Meadow Village (PWS No. 2384)

The Meadow Village water system serves approximately 2,050 residents through 820 connections. Water service is provided through a pressurized distribution system and elevated water storage tanks. Total storage capacity for the water system is 478,000 gallons from four tanks (a new tank is planned for installation during 2002). Water demand for the Meadow Village water system averaged 317,291 gallons per day (gpd) (220 gpm) during 2000. The maximum day demand during 2000 was 793,137 gpd (551 gpm), indicating a peaking factor of 2.5. The District prepared a Water Facility Plan for this system in 2001 and is presently making improvements to the water system per the recommendations of this plan (Allied 2001).

Table 1-2 presents data for each of the Meadow Village water system wells. The primary wells of this system include Meadow Village Nos. 1, 2 and 3. Hidden Village No. 1 is a small producer but provides an important source to the Hidden Village area, which is in a higher pressure zone than the Meadow Village wells. Hidden Village No. 2 and Blue Grouse are presently inactive. Hidden Village No. 2 could be used if needed. Blue Grouse is not connected to the water system.

Meadow Village Nos. 1, 2 and 3 and Hidden Village No. 1 are operated without treatment, and no treatment is presently required for these sources. Hidden Village No. 2 has historically been treated by filtration to remove sediment, although this equipment is presently off-line. The Blue Grouse well does not presently have any treatment equipment installed.

Meadow Village Nos. 1, 2 and 3, and Hidden Village No. 1 produce groundwater from a water-table alluvial aquifer consisting of glacial outwash deposits. The depth to groundwater ranges from about 10 to 20 feet and the base of the aquifer occurs at depths from 40 to 65 feet. The aquifer is thickest and most productive in the vicinity of the Meadow Village wells. Hidden Village No. 2 and Blue Grouse are bedrock wells, drawing groundwater from flowing artesian confined aquifers. Water quality due to natural mineral content is undesirable at both sites. Hidden Village No. 2 also produces clay particulates.

The Water Facility Plan prepared in 2001 for Meadow Village identified two additional well sites in the Meadow Village aquifer (Allied 2001). These well sites are designated Meadow Village Nos. 4 and 5, and are included in this SWDAR to meet the Source Water Protection requirements for new wells (DEQ Circular PWS-6). Table 1-2 documents the estimated parameters for these well completions. When installed, both wells will produce groundwater from the alluvial aquifer of Meadow Village. The well construction is anticipated to be most similar to Meadow Village No. 3, and a maximum pumping capacity of 350 gpm has been estimated for each well. It is likely that the actual pumping capacity will be equal to or less than 350 gpm, thus the work of this SWDAR will remain applicable to the wells.

Wastewater

The area of Meadow Village is served primarily by a centralized sewer collection system with a lagoon treatment system and filter treatment plant with chlorination facilities. Treated effluent from the lagoons is subsequently disinfected, filtered, and disinfected again before application as irrigation water. This final treatment step serves as a water reclamation process that is required for land application of treated wastewater in unrestricted areas, such as the Big Sky golf course. The governing rules for irrigation use of treated effluent are designed to provide for zero nitrogen total loading to groundwater. At present, irrigation water is applied to the Big Sky Golf Course. It will also be applied to the Yellowstone Club golf course when it is built in 2002 – 2004. During the non-irrigation months, filtered effluent is stored in a lined pond until it can be applied as irrigation water. Outside of the areas served by the centralized sewer system, primarily large acreage parcels use on-site sewage systems to treat and dispose of domestic wastewater.

1.3.2 Mountain Village (PWS No. 2385)

The Mountain Village water system serves a population of approximately 1,100 through 630 connections. Service is provided from a pressurized distribution system with elevated storage tanks installed on local hillsides. Table 1-3 presents well data for the Mountain Village water system. Originally this water system included Well Nos. 1 through 4. In the late 1990s, Well Nos. 5 and 6 were taken over from the Cascade Subdivision. A new well, designated as Well No. 7, is being installed during winter 2001-2002, and is located approximately 300 feet north of Well No. 4. A separate Source Water Delineation and Assessment Report has been prepared for Well No. 7 (Morrison-Maierle 2001).

There is one 1.5 Mgal storage tank used in the Mountain Village water system. Two booster stations provide additional hydraulic lift beyond that provided by the well pumps. The original storage tank, consisting of a 500,000 gallon tank on the side of Lone Mountain, could be used if needed, but is presently out of service

Well Nos. 1 through 4 are operated without water treatment. It is most likely that Well No. 7 also will be operated without treatment. Well Nos. 5 and 6 may be treated by chlorine oxidation (or other methods) at some future time in order to eliminate hydrogen sulfide odor in the water. Otherwise there are no treatment requirements for these wells.

Well Nos. 1, 2 and 3 produce groundwater from a water-table aquifer in till deposits, consisting of silt, sand, gravel and boulder mixtures. The depth to groundwater is about 10 to 15 feet at these well locations. The wells are in the range from 50 to 60 feet deep and are terminated at the first encounter of bedrock. Well Nos. 4, 5 and 6 produce groundwater from moderately deep confined bedrock aquifers. The aquifers are primarily within sedimentary rocks consisting of mudstone and sandstone, although a granitic (dacite) sill[4] appears to contribute significantly to the production from Well No. 4 (and the new Well No. 7). The static water level in Well No. 4 is about 40 feet. Static water is at or within 15 feet of ground surface in Well Nos. 5 and 6.

Wastewater

Most of the Mountain Village area is served by a centralized sewer system that ultimately connects to the Meadow Village treatment facility. Outside of the sewer collection service area, primarily large acreage parcels use on-site sewage systems to treat and dispose of domestic wastewater.

[4] A sill is an igneous rock formation formed by intrusion of magma, or molten rock, into a sedimentary rock mass after deposition of the sedimentary rocks. The sill is oriented parallel or sub-parallel to the bedding of the sedimentary rocks, and quite often will cross formations.

TABLE 1-2
MEADOW VILLAGE SYSTEM WELL DATA

Parameter	Well Name							
	Meadow Village No. 1	Meadow Village No. 2	Meadow Village No. 3	Hidden Village No. 1	Hidden Village No. 2	Blue Grouse	Meadow Village No. 4	Meadow Village No. 5
Figure 1-1 Map ID	MV #1	MV #2	MV #3	HV #1	HV #2	BG	MV #4	MV #5
PWS Source Code	002	003	004	006	--	005	Na	Na
Well Location NAD 83 Montana (m)	458711	458588	458458	457094	456417	457521	--------	----------
	114865	114856	114851	114907	114554	113350	--------	---------
Well Location, TRS	SWSWNE 36 6S3E	SESENW 36 6S3E	SWSENW 36 6S3E	SWSWNE 35 6S3E	SWNWSW 35 6S3E	SWSENE 2 7S3E		
GWIC No.	103505 (TW)	--	--	103499	103500/103501	155405	----	----
Water Right Permit No.	W122635 P122634 P107416	P122634 G122635 P107416	P122634 G122635 P107416	W122634 G122635 P107416	P061673	P076640	P107416	P107416
Pump Capacity (gpm)	180	180	230	30	125	None	350 (est.)	350 (est.)
Date Installed	8/1970	6/12/82	5/7/88	7/27/70	10/6/84 6/16/86	1/2/98		
Total Depth (ft)	50 (est.)	59	67	45	665	1250	60	60
Screen Interval (ft)	27 – 44 (est.)	37 – 56	53 – 67	34 – 44	502 – 643	1170 – 1250	40 – 60	40 – 60
Casing Diameter (in)	12	6	8	6	6	8	8	8
Surface Seal (ft)	--	--	20, cement	27, cement	500, cement	800, cement	28, cement	28, cement
Static Water Level (ft)	11	14	33	8	-210, flowing	-266, flowing	--	--
Pumping Water Level (ft)	19 (est.)	25	47	19.66	531	737	--	--
Test Capacity (gpm)	200	285	247	22	116	35	--	--
Drawdown (ft)	8	11	14	11.66	741	1003	--	--
Specific Capacity (gpm/ft)	25.0	25.9	17.6	1.9	0.16	0.03	--	--
Aquifer Type	Unconfined, Alluvium	Unconfined, Alluvium	Unconfined, Alluvium	Unconfined, Alluvium	Confined, Bedrock	Confined, Bedrock	Unconfined, Alluvium	Unconfined, Alluvium
Aquifer Sensitivity	High	High	High	High	Low	Low	High	High

TABLE 1-3
MOUNTAIN VILLAGE SYSTEM WELL DATA

Parameter	Well Name					
	Mountain Village No. 1	Mountain Village No. 2	Mountain Village No. 3	Mountain Village No. 4	Mountain Village No. 5	Mountain Village No. 6
Figure 1-1 Map ID	MTN #1	MTN #2	MTN #3	MTN #4	MTN #5	MTN #6
PWS Source Code	002	003	004	005	006	007
Well Location NAD 83 Montana State Plane (m)	451240	451267	451269	451051	450887	450644
	117522	117419	117189	117387	117823	117905
Well Location, TRS	SWSESE 19 6S3E	NWNENE 30 6S3E	SWNENE 30 6S3E	NENWNE 30 6S3E	NWSWSE 19 6S3E	NESESW 19 6S3E
GWIC No.	108809	108810	108811	103496	--	--
Water Right Permit No.	W122636	W133733	W122637	P061672	P100737	P100737
Pump Capacity (gpm)	240	95	114	123	200	500
Date Installed	8/18/72	8/22/72	8/29/72	11/16/84	8/29/94	7/30/96
Total Depth (ft)	64.5	50	63	400	212	200
Screen Interval (ft)	49.5 – 64.5	40 – 50	48 – 63	200 – 400	180 – 212	160 – 200
Casing Diameter (in)	8	8	8	8	8	8
Surface Seal (ft)	16, grout	16, grout	16, grout	20, cement	180, cement	60, cement
Static Water Level (ft)	10	9	10	40	0	14
Pumping Water Level (ft)	46.5	37	46	286	120	62
Capacity (gpm)	240	80	180	110	200	490
Drawdown (ft)	36.5	28	36	246	120	48
Specific Capacity (gpm/ft)	6.6	2.9	5.0	0.45	1.67	10.2
Aquifer Type	Unconfined, Till	Unconfined, Till	Unconfined, Till	Confined, Bedrock	Confined, Bedrock	Confined, Bedrock
Aquifer Sensitivity	High	High	High	Low	Low	Low

1.3.3 Aspen Groves Subdivision (PWS No. 4064)

Aspen Grove Subdivision is a small water system serving a population of approximately 35 people living in private homes. There are a total of 15-service connections, and the water supply is provided from Well Nos. 2 and 3, with Well No. 1 inactive. The wells pump to distribution and to a 230,000-gallon ground-level storage tank that is elevated above the service area on a hillside. There is no water treatment provided or required for the wells used in this water system. Table 1-4 provides data for the well supplies used in this system.

Groundwater is obtained from a confined bedrock aquifer consisting of mixed mudstone and sandstone. Static water level in the wells ranges from about 40 to 80 feet. The inactive Well No. 1 was installed to a depth of 180 feet in 1996 and has since become non-functional for unknown reasons. Well Nos. 2 and 3 were drilled much deeper, to 640 ft and 516 ft, respectively.

Wastewater

Aspen Grove Subdivision is within the Big Sky Sewer District and is served by a centralized sewer collection system, with treatment at the treatment facility located in Meadow Village.

1.3.4 Lone Moose Meadows Condominiums (EQ No. 98-1456)

Lone Moose Meadows Condominiums is a condominium complex affiliated with Yellowstone Club, LLC which has been annexed into the District. The water and wastewater systems are in the process of ownership transfer to the District. Lone Moose Meadows presently operates this system.

The condominium complex presently includes 28-units in about three service connections, serving a maximum population of about 70 people. It is likely the number of units will expand to 76 in the next few years, with a total of about 5 or 6 connections, and a population of about 190 people. The total development has been approved for up to 600 units, which may include about 40 connections and serve a total population of 1,500.

There are three wells installed at Lone Moose including one test well and two production wells. The test well is not connected to the water system, and is located within about 25 feet of production well Lone Moose No. 1. Production well Lone Moose No. 2 is located east of Well No. 1 about 250 feet. Table 1-5 presents data pertaining to these well installations. A ground-level storage tank with capacity of approximately 200,000 gallons is elevated on a hillside above the complex. There is presently no water treatment provided and there are no requirements for water treatment of the well supplies.

Lone Moose Well Nos. 1 and 2 are situated on unconsolidated till, but extend into bedrock formations, and produce groundwater from confined bedrock aquifers. In the area of these wells, bedrock formations consist of mixed mudstone and sandstone sedimentary rocks. Static water level ranges from 10 to 30 feet and the well depths range from 100 to 220 feet.

Wastewater

A centralized sewer collection system is used to transport domestic wastewater to an on-site sand-filter treatment system and absorption field discharge. The treatment facility and absorption field are located approximately 1,400 feet east of Lone Moose Well No. 2, and on the down-gradient side of the wells.

TABLE 1-4
ASPEN GROVE SUBDIVISION WELL DATA (PWS No. 4064)

Parameter	Well Name		
	Aspen Grove No. 1	Aspen Grove No. 2	Aspen Grove No. 3
Figure 1-1 Map ID	AG #1(inactive)	AG #2	AG #3
PWS Source Code	002	003	004
Well Location NAD 83 Montana State Plane (m)	455453	455495	455524
	114228	114215	114171
Well Location, TRS	SWSWSE 34 6S3E	SWSWSE 34 6S3E	SWSWSE 34 6S3E
GWIC No.	159764	169476	169477
Water Right Permit No.	P100681	P100681	--
Pump Capacity (gpm)	Inactive	18	50
Date Installed	7/30/96	6/4/98	6/4/98
Total Depth (ft)	180	640	516
Screen Interval (ft)	60 – 180	240 – 640	372-384,511-516
Casing Diameter (in)	6	6	6
Surface Seal (ft)	20, cement	23, cement	38, cement
Static Water Level (ft)	71	80	42
Pumping Water Level (ft)	100	186	55
Capacity (gpm)	45	18	80
Drawdown (ft)	29	106	13
Specific Capacity (gpm/ft)	1.55	0.17	6.15
Aquifer Type	Confined, Bedrock	Confined, Bedrock	Confined, Bedrock
Aquifer Sensitivity	Low	Low	Low

1.4 Water Quality

Source Water Quality

Available water quality data for the wells of this SWDAR are provided in Table 1-6. These data indicate some interesting contrasts in the native groundwater of the Big Sky area.

The Meadow Village wells drawing from an alluvial aquifer produce hard, calcium/magnesium-carbonate waters, with moderately high nitrate concentrations. Although nitrate concentration is much lower than the drinking water standard, it is significantly greater than normally exists in groundwater[5]. The levels observed in the Meadow Village wells, and in Hidden Village No. 1 indicate there is likely a nitrate loading to this groundwater system. The loading could be attributable to present and/or past land uses in the area.

The water analysis for the Mountain Village system shown in Table 1-6 appears to be a composite sample from Mountain Village Nos. 1, 2, and 3. These data apply to the shallow groundwater system located in the Mountain Village area. This groundwater is "fresh" and soft. It has substantially lower concentrations of dissolved ions than occur in the Meadow Village area. The nitrate concentration of 0.29

[5] A reasonable normal background nitrate level for pristine groundwater is 0.5 to 1.5 mg/L.

mg/L typifies a pristine, undisturbed groundwater. The purity of this water supply indicates plentiful recharge in the area and most likely short travel times from the recharge area to the wells.

Groundwater obtained from the deeper bedrock wells is more mineralized in general than the shallow groundwater[6]. Water quality data for Hidden Village No. 2 and Mountain Village Nos. 5 and 6 are similar to one another, which is not unexpected given the similar geology of these well completions. These three wells are completed in primarily marine sedimentary rocks. The groundwater from these wells is a sodium-carbonate type. It has moderate ion concentrations, but is soft because sodium dominates rather than calcium and magnesium. These three wells also are reported to produce groundwater with dissolved hydrogen sulfide gas. The Blue Grouse well in contrast is a hard water. It produces from a deeper continental sandstone formation. Sodium is plentiful in the water, but it is no longer the dominant ion based on the high hardness of the sample, which indicates significant calcium and magnesium concentrations. Minor but significant iron concentration occurs in both Blue Grouse and Hidden Village No. 2.

TABLE 1-5

LONE MOOSE MEADOW CONDOMINIUMS WELL DATA (EQ No. 98-1456)

	Well Name		
	Lone Moose No. 1	Lone Moose No. 2	Test Well
Figure 1-1 Map ID	LM #1	LM #2	Not Shown
PWS Source Code	--	--	NA
Well Location NAD 83 Montana State Plane (m)	453246	453199	--
	116086	116101	--
Well Location, TRS	NWSWSW 28 6S3E	NWSWSW 28 6S3E	NWSWSW 28 6S3E
GWIC No.	170083	187212	165874
Water Right Permit No.	--	--	--
Pump Capacity (gpm)			
Date Installed	11/11/98	11/16/00	7/23/97
Total Depth (ft)	200	100	220
Screen Interval (ft)	100 – 200	80 – 100	--
Casing Diameter (in)	12,8,6	12,8,7	6
Surface Seal (ft)	25, ben-cement	20, bentonite	20, bentonite
Static Water Level (ft)	29	12	29 (est.)
Pumping Water Level (ft)	--	48	215
Capacity (gpm)	100	200	15
Drawdown (ft)	--	36	186 (est.)
Specific Capacity (gpm/ft)	--	5.6	0.08
Aquifer Type	Confined, Bedrock	Confined, Bedrock	Confined, Bedrock
Aquifer Sensitivity	Low	Low	Low

[6] Where data are missing, geochemical inference is used to estimate the type of water. It is most likely that a well with high sodium will be soft (low hardness) and have relatively low concentrations of calcium and magnesium. In contrast, a hard groundwater (high hardness) will tend to be dominated by calcium and magnesium rather than sodium.

TABLE 1-6
SOURCE WATER QUALITY

Parameter[1]	Meadow Village No. 1[2]	Meadow Village No. 2[2]	Meadow Village No. 3[2]	Hidden Village No. 1[2]	Hidden Village No. 2[3]	Blue Grouse[4]	Mountain Village[5] (Composite)	Mountain Village Nos. 5 & 6[6]
Date	9/9/99	9/17/99	8/26/99	7/21/99	9/1/95	7/15/97 8/11/97[x]	1/13/95	7/29/96
Temperature (°C)	8.0	8.0	7.5	7.5	7.7	13.5[x]	--	‘--
pH (field/lab) (std. units)	7.4 / 7.8	7.1 / 7.8	6.9 / 8.2	7.4 / 7.6	-- / 10.5	7.6[x] / --	-- / 7.0	‘-- / 9.4
Conductivity (µS/cm)	507	541	564	414	--	485[x]	143	290
Total Dissolved Solids	334	358	371	274	--	358	--	190
Alkalinity (mg/L $CaCO_3$)	196	202	88	200	220	--	61	150
Hardness (mg/L $CaCO_3$)	211	244	157	206	--	257	53	30
Langlier Index (-)	0.37	0.40	0.12	0.16	--	--	--	--
Bicarbonate	196	202	88	200	270	--	--	--
Carbonate	<1	<1	<1	<1	--	--	--	--
Chloride	16.1	25	31.2	4.9	--	1.4	--	<5
Fluoride	0.1	0.1	0.1	0.2	--	0.8	--	0.44
Nitrate + Nitrite (mg/L N)	3.9	2.8	3.6	3.3	0.11	--	0.29	<0.05
Sulfate	21	37	29	12	20	<0.04 (S^-)	--	<10
Calcium	61	72	34	61	--	--	15.9	1.4
Magnesium	14	15	17	13	--	--	3.2	6.4
Sodium	5.60	5.00	1.10	3.10	100	38.9	7.2	65
Potassium	0.80	1.00	1.00	1.00	--	--	--	<1
Iron	<0.15	<0.15	<0.15	<0.15	0.23	0.8[x]	ND	0.07
Manganese	<0.05	<0.05	<0.05	0.05	--	0.07	ND	<0.01

[1]Units are mg/L unless listed otherwise. [2]From Western Groundwater Services (1999). [3]From Baldwin (1996).
[4]From MSE-HKM (1997). [5]From MDEQ database (Melissa Levens by email). [6]From District (Gaston Engineering).

Safe Drinking Water Act Compliance

The District water systems meet all water quality regulations according to the Safe Drinking Water Act. MDEQ staff conducted a search of water quality data submitted by the District, and also the occurrence of violations of water quality standards. No data on record show the District to have exceeded any inorganic, organic or radionuclide water quality standards. One violation from August 2001 existed on record for the Meadow Village water system related to the Total Coliform Rule. Total coliform was present in a sample, however, fecal coliform was absent. This violation was resolved through repeat sampling. A total of nine follow-up samples over a two-month period showed no presence of coliform and by inference, of fecal coliform, in the water system.

Consumer Confidence Reports

The District has prepared a consumer confidence report (CCR) on water quality during each year since this report became a requirement 1999. The most recent CCR prepared by the District is provided in Appendix C. This report summarizes the water quality violations and the occurrence of contaminants in drinking water. The District has shown through compliance monitoring that the drinking water sources meet and normally exceed the minimum water quality standards. In certain cases, contaminants are present in the drinking water, such as nitrate and sulfate, but the concentrations are substantially below the allowed levels.

TMDLs and the 303(d) List

In compliance with the federal Clean Water Act, the state of Montana Department of Environmental Quality (DEQ) is in the continuous process of conducting water quality assessments on surface waters, such as the Gallatin River and tributaries. These assessments have the purpose of identifying the impaired or threatened[7] condition of the waterbody with respect to designated uses (e.g., drinking, swimming, agriculture, industry).

Every two-years since 1992 the state has submitted a list of impaired and threatened waters to EPA, referred to as the 303(d) list. A draft 303(d) list was prepared in April 2000 and is in the review process (DEQ 2000). The 303(d) list submitted by the state must include a prioritization of the listed waterbodies for the development of plans to improve water quality or prevent future threats to water quality. Best management practices are normally included in the plans as activities to mitigate poor water quality or threatened status. Some of these plans involve development of the total maximum daily load (TMDL) for selected pollutants, and consequently, the plans have been referred to as TMDL plans. A TMDL limits the loading of a pollutant that can occur into the waterbody while meeting water quality standards[8]. Many waterbodies that appear on the 303(d) list will not actually have TMDLs developed, as other management methods will be implemented to improve water quality.

[7] An impaired water presently does not meet standards. A threatened water is likely to violate standards in the near future.

[8] Ammonia and nitrate in municipal wastewater discharges are examples of pollutants that may be managed by development of TMDLs. Regulation of individual discharges is addressed in the facility's Montana Pollutant Discharge Elimination System (MPDES) wastewater permit.

The West Gallatin River in the area of Big Sky appears on the 303(d) list as an impaired stream because it only partially supports fish and other aquatic life[9]. Nutrient loading, siltation, bank erosion, general fish habitat degradation, and algal growth are identified as the probable causes of impairment. Forestry, land development, urban/highway runoff, and on-site sewage systems are identified as the probable causes.

[9] 303(d) list includes: West Gallatin River; Middle Fork West Gallatin River; South Fork West Gallatin River.

2 DELINEATION

Delineation consists of mapping Source Water Protection Areas – protection regions that surround the water supply wells. The protection regions provide a focus for gathering data on potential contaminants and planning management activities. The smaller inner regions receive the highest level of protection. The larger more distant regions are managed less stringently, relying partially on natural purification should a contamination event occur.

There are four regions that may be required for delineation of water supply wells, collectively forming the Source Water Protection Areas. These regions include:

- <u>Control Zone</u> This region is a circular area with a radius of 100-feet. It is centered on the well, and is delineated for all types of wells.

- <u>Inventory Region</u> In unconfined or semi-confined aquifer settings, the Inventory Region is computed based on groundwater hydraulics. It surrounds the well and extends up-gradient (“upstream”) to the 3-year time-of-travel boundary for groundwater to flow to the well (i.e., all groundwater within the Inventory Region flows to the well in a time period of 3-years or less). In confined aquifers, the Inventory Region is delineated as a circular area with a radius of 1,000 feet, centered on the well.

- <u>Recharge Area</u> This region includes the entire area contributing water to the well (i.e., the recharge area), and is mapped for all types of wells. The Recharge Area may coincide with a topographic boundary, but not necessarily. It is determined either through flow-balance calculations or hydrogeological boundary mapping.

- <u>Surface Water Buffer</u> In unconfined or semi-confined aquifer settings, it is also necessary to map all hydraulically connected surface waters flowing through the Inventory Region. These surface waters may act as conduits for the transport of acute contaminants, such as pathogens and nitrate. A ½-mile wide buffer area on either side of the surface water body is mapped for 10-miles upstream from the Inventory Region. It is assumed that only contaminant sources of pathogens and nitrate in this region could possibly affect wells. The Surface Water Buffer is not mapped for confined aquifer wells.

2.1 Delineation Methods and Limitations

The methods of delineation and the associated errors, or limitations, vary by Source Water Protection Area, and are discussed in this section. The implications of these limitations are that boundaries of Source Water Protection Areas should not be considered exact, but more as guidelines. As a precautionary measure, important land uses occurring in proximity to Source Water Protection Area boundaries should be evaluated as if they occur in the inner-most zone (more stringently managed). As new information is learned about the hydrology of an area, it can be beneficial to revise the delineation of Source Water Protection Areas. Such revisions are particularly necessary when evaluating water supply wells. Source Water Protection Areas for water supply wells can be changed dramatically by the installation of a new neighboring well that exerts an interference drawdown effect on the existing well.

2.1.1 Control Zone

The control zone is mapped by drawing a 100-ft radius circle around the well. There is little potential for error in determining the control zone. A wrong well location will introduce error into the location of this mapped area.

2.1.2 Inventory Region

Unconfined and Semi-Confined Aquifer Wells

For unconfined and semi-confined aquifer settings, the Inventory Region is based on the physics of groundwater flow to a water supply well. Complex mathematical formulas coded in a computer program are used as a basis for mapping of the Inventory Region. Input data are required based on direct and indirect measurements of the groundwater flow system. To delineate Inventory Regions for unconfined and semi-confined aquifer wells, a computer program called TWODAN (Fitts 1999) was applied and input data were developed from existing information on the area hydrogeology[10]. For the Meadow Village wells, however, a more rigorous modeling effort was completed that used the U.S. Geological Survey program called MODFLOW (Harbaugh and McDonald 1996)[11].

There are a variety of ways to introduce errors into the Inventory Region delineation[12]. Base mapping data that are used to set up the models may not be consistent with one another. For example, geological mapping data may not match up correctly with stream channel mapping data. Simplifying assumptions concerning the physics of the groundwater system are also built into the computer model. No computer model can exactly represent the complexities of a groundwater flow system. Aquifer hydraulic data, upon which the model is based, also have associated uncertainty, and the true spatial distribution of these data cannot be known or represented. Time-varying aspects of the groundwater flow system, such as the direction of flow, are normally not well known and can be represented normally by use of a time-average value.

Confined Aquifer Wells

The Inventory Region for confined aquifer wells, as noted above, is drawn as a circular area with a radius of 1,000 feet, centered on the well. There is little chance for error in mapping this area, other than a wrongly located well.

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[10] TWODAN applies the analytic element method, which is much more sophisticated than an analytical formula for flow to a well. TWODAN can represent multiple pumping wells in a non-uniform flow field with boundary conditions and heterogeneity of aquifer properties. The model is, however, run in a steady-state mode.

[11] MODFLOW is probably the most common of the 3-dimensional numerical groundwater flow models. It provides more flexibility in the model setup to represent groundwater flow systems. It also requires more input data and is more complex to use. It has been applied in the Meadow Village aquifer so that it can be used for wellfield capacity evaluations at a later time.

[12] Despite the opportunity for introduction of error into groundwater computer modeling, the approach taken is technically consistent with the standard of practice for the field of quantitative hydrogeology. The application of TWODAN and MODFLOW in Source Water Protection Planning substantially exceeds the minimum requirements imposed by state agencies, including Montana DEQ.

2.1.3 Recharge Area

Recharge Areas were mapped based on the topographical boundaries of the various watershed sub-basins that occur in the Big Sky area[13]. This approach was taken due to the complexity of the groundwater flow system. For many of the confined aquifer wells, the recharge area is most likely a discontinuous region associated with surface outcrops of aquifer formations, constituting a small proportion of the sub-basin area. For these wells, it is more conservative and feasible to simply designate the Recharge Area as the associated sub-basin, or some proportion of the sub-basin. For the unconfined wells, the Recharge Area is also reasonably estimated using the sub-basin boundary, and will be equal to or smaller than the sub-basin (when delineated with consideration of the water balance for the sub-basin and the production rate from the well).

The sub-basin areas were delineated using the Spatial Analyst Extension of ArcView GIS (ESRI 1999)[14]. Digital Elevation Models (DEMs) were downloaded from the U.S. Geological Survey to complete this work. The DEMs consist of 30-meter by 30-meter grid cells with a grid-centered elevation. Hydrologic Analysis Tools in the Spatial Analyst Extension were used to map topographic divides for sub-basins. Sub-basins were limited on average to a total area of approximately 1,000 acres or greater[15].

There are several limitations that apply to the delineation of the sub-basins and, consequently, the Recharge Areas. Delineations are based on mapping data, such as the locations of stream channels and the land surface elevations. There are errors associated with these data, related to the accuracy of the original maps and changes in the land surface that may have occurred since the maps were first created. It is possible that stream channel locations may have associated errors of ±500-feet, which equates to ¼-inch on a 1:24,000 topographic map. DEMs have an associated vertical accuracy of ±7-meters and a horizontal accuracy of ±30-meters.

2.1.4 Surface Water Buffer

The Surface Water Buffer is based on existing maps of surface waters that cross the Inventory Region for wells installed into unconfined or semi-confined aquifers. Specialized computer software (ArcView GIS 3.2, ESRI 1999) was used to draw ½-mile wide buffers on either side of these surface waters and for a distance of 10-miles upstream (or the top of the watershed, whichever is shorter). Occurrence of errors may result from inaccurate mapping of the area. If the maps do not show all of the surface waters or the surface waters are wrongly located, errors can result. The Surface Water Buffer is also limited to ½-mile wide buffers and a distance of 10-miles upstream by assumption. It is possible, but unlikely, that contaminants could enter the water source from beyond the ½-mile buffer and from beyond the 10-mile mark on the water body.

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[13] Delineation of recharge areas for the Meadow Village aquifer wells (MV-1 through MV-5) was based on the results of MODFLOW computer simulation. Limitations associated with this technique are as described for the Inventory Region of unconfined and semi-confined wells.

[14] This work was completed by DTM Consulting, Inc. of Bozeman, Montana.

[15] The GIS software can and will delineate any area enclosed by topographic divides, which can result in small sub-basin areas, on the order of a few acres in size. In order to create a more tractable GIS database, the size of the sub-basins that are mapped is limited. In this application, the minimum size of 1,000 acres appeared reasonable.

2.2 Hydrogeological Conceptual Model

In order to interpret and map the recharge areas to water supply wells, it is necessary to first evaluate how the groundwater flow system "works". This evaluation is referred to as the hydrogeological conceptual model [for the groundwater flow system feeding the water supply wells]. This section summarizes the hydrogeological conditions of the project area based on existing information obtained from the sources listed in Table 2-1, and also cited in the report references. Additional details concerning the conceptual model of the area are also provided in the sections pertaining to delineation mapping which follow.

TABLE 2-1
HYDROGEOLOGICAL DATA SOURCES

Authors	Type of Study	Area
Big Sky County Water and Sewer District	Water system records for wells and water use	Mountain and Meadow Village areas
Kellog and Williams (1997)	Geological Mapping 1:100,000	Ennis 30'x 60' Quadrangle
Montana Bureau of Mines and Geology Groundwater Information Center (GWIC)	Well logs	Mountain and Meadow Village areas
Baldwin (1996, 1997)	Report to MDEQ and Master's Thesis: includes field data/maps of hydrogeology	Mountain and Meadow Village areas
Morrison Maierle (1986, 2001) MSE-HKM (1997) Western Groundwater Services (1999)	Well installation and/or testing reports by consultants	Mountain Village, Hidden Village, Blue Grouse Well, Meadow Village
Montana Natural Resources Information System (NRIS)	GIS database library for roads, streams, land use, and elevation	Mountain and Meadow Village areas
NOAA Western Regional Climate Center	Climate monitoring data consisting of monthly summaries	Station: Big Sky 3S
USDA NRCS Bozeman Office	SNOTEL climate monitoring	Station: Lone Mountain

2.2.1 Geology

Big Sky is an area of complex mountain geology. Information pertaining to the geology of the area is presented on Figures 2-1 through 2-7. Geological maps appearing on Figures 2-1 and 2-2 were prepared by Kellog and Williams (1997) and were obtained in Arc View GIS format directly from the U.S. Geological Survey (USGS). Cross sections presented in Figures 2-3 through 2-7 are based on the geological surface mapping, land surface topography (from USGS topo maps), and well logs for the project area obtained from the Groundwater Information Center at the Montana Bureau of Mines and Geology. Copies of the well logs are provided according to each cross section in Appendix C.

Geological formations of the Big Sky area consist primarily of unconsolidated deposits of clay, silt, sand and gravel, and older consolidated sedimentary rocks (bedrock). Both types of formations are used as aquifers throughout the area, and are used by the wells of this report. Most of the area is dominated by bedrock formations, which are complexly folded and faulted. The unconsolidated deposits exist on top of the bedrock, as formed from stream and glacier deposition.

Meadow Village geology is shown on Figure 2-1 and in cross sections on Figures 2-4 and 2-5. This area is centered on the hinge of a syncline (Big Sky Syncline), or downward fold of the bedrock formations. The hinge is oriented from about west to east. The syncline fold has a gentle south limb, a moderately broad hinge area, and a steep north limb. The north limb steepens up the mountain side towards the Spanish Peaks. Unconsolidated deposits of clay, silt, sand and gravel occur in the valley area, and are deposits from streams and historic glaciers. These deposits may reach up to 60-feet in thickness. The Meadow Village wells MV-1 through MV-3, and HV-1 produce groundwater from an aquifer in these deposits. The other wells shown, including Aspen Grove Nos. 1, 2 and 3, Hidden Village No. 2, and Blue Grouse produce groundwater from bedrock formations.

Mountain Village geology is shown on Figure 2-2 and in cross sections on Figures 2-6 and 2-7. The Big Sky Syncline of the Meadow Village area is shown to the north of the Mountain Village. Mountain Village area bedrock is folded into a group of small anticline (upward fold)-syncline folds with hinges oriented south to north. The structure is somewhat of an anomaly without an obvious explanation (personal communication K. S. Kellog), but reflects west – east compressive forces. Till formed by glaciers rests on top of bedrock over large areas of Mountain Village including the commercial area near Lake Levinsky. The till likely includes stream deposits that are more productive as aquifers than a typical till, which is usually non-productive. Mountain Village wells MTN-1 through MTN-3 produce groundwater from till deposits. Wells MTN-4 through MTN-6 produce groundwater from bedrock, as do Lone Moose Nos. 1 and 2.

It is noteworthy that in relatively small proportion, some of the bedrock formations are comprised of igneous intrusive rocks formed by upward movement of molten rock, or magma, and subsequent spreading into the sedimentary bedrock formations. Mountain Village Well No. 4 appears to produce groundwater from these formations. These rocks are identified by map symbols Kd and TKg where they appear at land surface on Figures 2-1 and 2-2. Both formed at similar times, although the TKg unit is younger than the Kd unit. The Kd rocks are part of the Fan and Lone Mountains instrusion and occur primarily in the Lone Mountain area[16]. The TKg rocks are less abundant and occur near Lone Moose Meadows and in the Meadow Village area[17]. Encounters of igneous rocks in the Mountain Village area could be either Kd or TKg and may exist in one or more of the sedimenatary formations. Encounters of igneous rocks in the Meadow Village area are most likely TKg.

2.2.2 Hydraulic Properties

The analysis of groundwater flow through a medium, either bedrock or loose sand and gravel, has been under study for many years. The primary mathematical model used to describe groundwater flow (Darcy's Law) is based on a rock-fluid property referred to as hydraulic conductivity, normally denoted by the letter K. The value of K when multiplied by the formation saturated thickness (typically denoted

[16] Gray to greenish-gray porphyritic dacite that weathers to light gray or tan. Phenocrysts are dominantly plagioclase with lesser hornblende, biotite, and quartz.

[17] Black, medium-grained plagioclase-clinopyroxene gabbro that typically weathers into spheroidal blocks, and weathers to grussy orange-brown soil. Intrudes upper and lower Cretaceous rocks.

by letter b) is referred to as the transmissivity, denoted by the letter T, and is also a rock-fluid property[18]. Both K and T are rock-fluid properties because they depend on the ease of a fluid to pass through the medium, which is affected by the fluid's viscosity and the connection of open channels in the medium. Based on extensive data sets that report values for K and T, it is known that solid rocks and fine-grained unconsolidated rocks, such as silt and clay, have low values, whereas loose sand and gravel can have exceptionally high values[19]. This correlation of property values indicates that groundwater flow rates are slowest in bedrock and deposits of silt and clay, and fastest in deposits of loose sand and gravel.

This section reports information on values for K and T that were determined from data collected in the Meadow and Mountain Village area wells. Some of these data were obtained by proper well hydraulic testing and interpretation methods. Some of these data were obtained by driller tests, and it is likely the quality of these data for estimating hydraulic properties is poor. The results presented require analyst interpretation, and therefore incorporate a subjective element. It is expected that other qualified analysts may make estimates from the same data that vary by factors of 2 to 3 from those presented here. The data are summarized in Table 2-2 for well tests in unconsolidated formations. Table 2-3 provides a summary of data for well tests in bedrock formations.

It is noteworthy that the fundamental property determined from well tests is the transmissivity[20]. The results of Tables 2-2 and 2-3 indicate this parameter is substantially greater for unconsolidated formations in comparison to bedrock formations. Transmissivity ranges from 1,170 to 27,400 ft^2/d for unconsolidated formation well tests. It is substantially lower, ranging from a low of 3 ft^2/d (Blue Grouse) to a high of 2,730 ft^2/d (MTN-6) in bedrock formation well tests.

[18]Because T = K x b, a moderate or low value of K could result in a large T if the thickness, b, were large, or vice versa.

[19]Bedrock formations of open-cavern limestone and fractured basalt are noted to have extremely high K and T values, but these formations are exceptions, and limestone and basalt can also be low K and T formations.

[20] Hydraulic conductivity is inferred from transmissivity by computing K = T/b, where b is thickness. Unfortunately, the value of b can be difficult to estimate, particularly in bedrock formations that transmit groundwater in fractures.

TABLE 2-2
HYDRAULIC DATA FOR UNCONSOLIDATED FORMATIONS

Well Name	Test	Transmissivity (ft^2/d)	Thickness (ft)	Conductivity (ft/d)
HV-1	24-hr constant rate, 7/21/99	1,170	10	120
MV-1	24-hr constant rate, 9/23/99	27,400	26	1,050
MV-2	4-hr step w/recovery, 9/17/23	13,500	21	640
MV-3	4-hr step w/recovery, 8/26/99	8,800	33	270
LMTN-2	Driller log	5,700	28	200
MTN-1	24-hr constant rate, 2/5/86	7,060	15	470
MTN-2	24-hr constant rate, 2/25/86	2,950	15	200
MTN-3	24-hr constant rate, 2/16/86	2,410	15	160

Determination of transmissivity was based on Cooper-Jacob method and drawdown v. time data, or using the approximate Cooper-Jacob method based on specific capacity of test data (Driscoll 1986). Thickness is estimated from well log and conductivity is computed as transmissivity divided by thickness.

TABLE 2-3
FORMATION HYDRAULIC DATA FOR BEDROCK WELLS

Well Name	Test	Transmissivity (ft^2/d)	Thickness (ft)	Conductivity (ft/d)
HV-2	Driller Log	40	141	0.3
BG	89.5-hr constant rate, 8/7/97	3	14	0.2
AG-1	Driller log	415	30	14
AG-2	Driller log	45	100	0.5
AG-3	Driller log	1,645	118	14
Lone Moose Test Well	Driller log	20	48	0.5
LM-2	Driller log	1,500	13	115
MTN-4	48-hr constant rate, 12/18/85	1,450	82	18
MTN-5	24-hr constant rate, 2/21/97	450	32	15
MTN-6	24-hr constant rate, 7/26/96	2,730	40	70

Determination of transmissivity was based on Cooper-Jacob method and drawdown v. time data, or using the approximate Cooper-Jacob method based specific capacity of test (Driscoll 1986). Thickness is estimated from well log and conductivity is computed as transmissivity divided by thickness.

2.2.3 Groundwater Recharge

Groundwater recharge was estimated for infiltration due to snow melt and rain based on two methods. The results are summarized in Table 2-4 and analysis worksheets are provided in Appendix D.

A monthly water balance method was applied using historical monthly climate data obtained for the Lone Mountain and Big Sky 3S stations shown on Figure 1-2. These results pertain to the Mountain Village and Meadow Village areas, respectively. The Mountain Village area recharge rate substantially exceeds that for the Meadow Village area due to the higher precipitation that occurs at higher elevation.

A second method was applied based on stream base flow measurements as reported in Baldwin (1996). The stream base flow reported in September 1995 is assumed to represent entirely groundwater discharge to surface water. Is it also presumed that this rate remains “about” steady through the year. The total watershed area was determined by GIS methods and USGS DEM data for the area. The recharge rate as determined by this method is intermediate to values based on a monthly water balance, indicating that overall, the values appear to be reasonable estimates.

TABLE 2-4
GROUNDWATER RECHARGE ESTIMATES

Monthly Water Balance Method				
Site Location	Annual Precipitation (in)	Runoff (in)	Actual Evapotranspiration (in)	Groundwater Recharge (in)
Lone Mountain	37.6	9.4	14.6	13.6
Big Sky 3S	19.4	2.9	13.9	2.6
Stream Base Flow Method				
Location	Date	Flow (cfs)	Watershed Area (acres)	Groundwater Recharge (in)
West Fork above W. Gallatin River	September 1995	27.7	50,533	4.8

2.2.4 Groundwater Flow Direction

Mapping of groundwater elevations as a method to determine groundwater flow direction is provided by Baldwin (1996 and 1997) for parts of the Big Sky area, and is presented later in this report (Figure 2-17). These results agree with a general west to east, "downhill", flow direction for groundwater in the Big Sky area. Locally flow direction is oriented toward stream channels, and ultimately, groundwater in the Big Sky area discharges to tributaries of the West Gallatin River.

At Mountain Village and other highland areas of Big Sky, groundwater flow direction occurs from higher elevations to the Middle Fork channel. In the Meadow Village area, groundwater flow occurs from higher elevations toward and parallel to the West Fork channel. East of Meadow Village the West Fork channel cuts through bedrock, and it is likely that the majority of groundwater in the Meadow Village aquifer discharges into the stream channel west of this point.

Although it is common for groundwater flow direction to shift by 5 to 25 degrees in direction throughout the year, it is anticipated that natural groundwater flow pathways in the Big Sky area are more consistent. This consistency in flow direction is anticipated because of the large topographic relief, the absence of irrigation canals and large irrigation operations, and the generally small size of surface streams. Seasonal changes in groundwater flow direction are expected in the vicinity of municipal wells that may run for longer periods during the summer months. In particular, the Meadow Village Well Nos. 1, 2 and 3 likely influence groundwater flow direction in the summer months due to longer operating periods.

Hydraulic gradients in the Big Sky area are relatively steep by comparison to larger valleys. Low transmissivity bedrock formations on mountainous hillsides may have hydraulic gradients on the order of 0.1 to 0.2. More transmissive bedrock units under the same conditions will have a lower hydraulic gradient, in the range from 0.05 to 0.1. The Meadow Village aquifer, which is the most transmissive formation in the area has hydraulic gradients in the range from 0.01 to 0.05. By comparison, a highly transmissive aquifer in a larger valley may have a hydraulic gradient ranging from 0.001 to 0.005.

2.3 Confined Wells Delineation

Figures 2-8a through 2-8c present delineation mapping for confined aquifer wells. Control Zones are shown as 100-ft radius circles centered on the well. Inventory Regions are based on 1,000-ft radius circles centered on the well, but are modified for overlap with neighboring wells. Recharge Areas are reasonably estimated within the watershed of the well. In several cases it is unreasonable to include the entire watershed. Effective limits on the Recharge Areas are shown by dashed lines pertaining to Lone Moose Nos. 1 and 2, the Aspen Grove wells and Hidden Village No. 2, and the Blue Grouse Well. These limits are conservative and it is expected that the Recharge Areas shown substantially exceed the actual recharge areas.

2.4 Unconfined Wells Delineation

This section presents delineation mapping for Mountain Village Nos. 1, 2 and 3, and Hidden Village No. 1. These wells produce groundwater from unconfined or semi-confined aquifers. Delineation areas for these wells are presented in Figures 2-9a through 2-9c. The Control Zone is mapped as a 100-ft radius circle centered on the well. The Inventory Region was mapped based on the 3-year time of travel for groundwater to flow to the well using the TWODAN analytic element model, which is described in detail below. Where the Inventory Region of two or more wells has a common boundary, the area has been "lumped" to include the wells. The Recharge Area for these wells is mapped as the local watershed of the well, and was truncated to a practical limit for Hidden Village No. 1. It is expected that the Recharge Areas shown substantially exceed the actual recharge area for the wells. Surface water buffer areas for the wells were mapped using Arc View GIS, as described earlier (ESRI 1999). Surface Water Buffer areas were also truncated at the watershed boundaries.

2.4.1 TWODAN Inventory Region Delineation

TWODAN is an analytic element model for groundwater flow under steady-state conditions (Fitts 1999). It can represent a variety of complex features, including non-uniform groundwater flow, changes in aquifer hydraulic properties with location, boundary conditions, such as streams, and multiple pumping wells. Two separate TWODAN models were created to map the Inventory Regions of Mountain Village Nos. 1, 2, and 3, and Hidden Village No. 1, respectively.

Mountain Village Nos. 1, 2, and 3

Model setup and simulation results for Mountain Village Nos. 1, 2 and 3 are shown on Figures 2-10 and 2-11. The geological map showing the extent of till and the surface hydrology mapping data available in GIS format were used as a model base. The aquifer was assumed to have a maximum thickness of 15.5 meters, or 50 feet, based on the saturated thickness that exists at the well locations[21].

Groundwater hydraulic properties, which are annotated onto Figure 2-10, were determined based on well tests reported earlier in this report. In setting up the model, three zones of different hydraulic conductivity were entered: zone 1 represents bedrock; zone 2 represents upper mountain till; and zone 3 represents the productive aquifer of the well installations and the Lake Levinsky area. It was assumed that the flat lying area where the wells are located was of higher transmissivity than the mountain till

[21]Use of metric system units occurs in this report because the units of base maps are meters. While it is possible to easily display maps in units of feet within Arc View GIS, it is not possible to easily use units of feet when constructing the groundwater models. Consequently, the base map for modeling uses a length unit of meters and this requires that all other model input be based on meters as well.

deposits. This region in the flow system likely exists because the Mountain Village wells indicate higher transmissivity than is typical of till deposits. Its geometry was based on the land surface topography.

Surface water features including stream channels and Lake Levinsky were represented by "line-sinks" set to constant hydraulic head values based on USGS topography. Groundwater flow can occur to or from these features in the model. As configured, all of the line-sink features were locations of groundwater discharge.

Infiltration recharge was based on the monthly water balance method when applied to the Lone Mountain data. It was reduced to account for a thinner groundwater flow system. This adjustment is needed because the actual flow system that would accept the entire recharge rate is much thicker than the 15.5 m thickness used in the model.

Pathlines shown on Figure 2-11 are drawn for steady-state pumping at the maximum production rates of the wells. Each pathline shows a 3-year time-of-travel for groundwater, with arrowheads drawn at 1-year intervals. The well pumping rates used in the model were: 240 gpm – Well No. 1; 80 gpm – Well No. 2; and 180 gpm – Well No. 3. The pathlines show that down-mountain groundwater flow provides recharge to the wells based on the present model configuration. The configuration of these pathlines is directly related to the selected model setup. Although this model setup was chosen to best represent the groundwater flow system, differences may exist between the actual and modeled conditions.

Hidden Village No. 1

Model setup and simulation results for Hidden Village No. 1 are shown on Figures 2-12 and 2-13. The geological map showing the extent of unconsolidated deposits in the Meadow Village area, and the surface hydrology GIS data were used as a model base map. For the purposes of delineation modeling, the aquifer was assumed to have a maximum thickness of 9.15 m, or 30 ft, which is representative of the saturated thickness at the location of Hidden Village No. 1.

Groundwater hydraulic properties were determined based on well testing data reported earlier. Three hydraulic conductivity zones were established in the model: zone 1 represents bedrock formations; zone 2 represents lower transmissivity alluvial deposits; and zone 3 represents high transmissivity alluvial deposits. Hidden Village No. 1 is located within the zone 2 region.

Surface water features represented by line-sinks were included in the model only at the eastern boundary of the alluvial deposits, as annotated onto Figure 2-12. Although exchange between groundwater and surface water likely occurs elsewhere within the model area, a more conservative (i.e., larger) delineation area is determined if the surface water features are not included.

Infiltration recharge was applied based on the rate determined from the monthly water balance method for the Big Sky 3S station. It was reduced slightly to account for the thinner aquifer represented in the model.

Pathlines for Hidden Village No. 1 are shown on Figure 2-13, and are drawn for steady-state pumping at the maximum production rate of 30 gpm. The pathlines extend up-gradient for a 3-year time-of-travel, with arrowheads located at 1-year intervals. The configuration of these pathlines is directly related to the selected model setup. Although this model setup was chosen to best represent the groundwater flow system, differences may exist between the actual and modeled conditions.

2.5 Meadow Village Aquifer Wells Delineation

This section presents delineation for Meadow Village Well Nos. 1 through 5, and is based on computer modeling using MODFLOW. Part of this work includes delineation for two future well sites, identified as MV #4 and MV #5, in order to fulfill the Source Water Protection requirements for new wells, as described in MDEQ Circular PWS-6.

Delineation areas for MV #1 through MV #5 are presented on Figures 2-14a and 2-14b. Control zones are mapped as 100-ft radius circles centered on the well location. Inventory Region boundaries are based on the time-of-travel for groundwater to flow to the wells, as determined by numerical modeling using MODFLOW and particle tracking using MODPATH. Based on modeling results, the maximum travel time for groundwater from recharge area to well location ranges from about 5- to 11-months. Consequently, the Inventory Region defines a time-of-travel that ranges only from 5- to 11-months, rather than 3-years, and the Recharge Area coincides with the boundary of the Inventory Region. Inventory Regions and Recharge Areas were not mapped on an individual well basis because the areas are in direct contact with one another. The individual areas can be identified in the modeling documentation provided below.

2.5.1 <u>MODFLOW Delineation</u>

MODFLOW is a long-established groundwater computer model written by the U.S. Geological Survey (USGS). It was first published in the mid-1980s and was subsequently modified and republished in 1996 (Harbaugh and MacDonald 1996). The version used here was run from within the Visual MODFLOW graphical user interface (Waterloo Hydrogeologic 1999), and is called MODFLOW-2000.

MODFLOW provides for the calculation of flow rates and hydraulic head throughout the modeled groundwater flow system. A supplementary program, called MODPATH, is used to draw groundwater pathlines based on time of travel of groundwater (Pollack 1994). MODPATH was used to map delineation areas based on the MODFLOW simulation of the Meadow Village aquifer.

The calibration of MODFLOW to observations of the actual system is the most difficult aspect of groundwater computer modeling. In this MODFLOW application a relatively new method was applied that provides for "automatic" parameter estimation, or inverse modeling. Although this theory has been put forth for decades, its implementation in groundwater modeling has just begun. WinPEST is a computer program written by Doherty (2002) that provides parameter estimation and has been incorporated into the Visual MODFLOW interface program.

<u>Input Data</u>

The first step in the modeling effort was to assemble the field data pertaining to the model area. These data are summarized below.

Model Domain Figure 2-1 is a geological map that shows the extent of unconsolidated deposits in the Meadow Village Area. These areas are identified by map symbols Qal and Qg. The model domain considered was limited to this area, although the Qal deposits were not included approximately west of the North Fork – Middle Fork confluence area. The Qal deposits are narrow and thin west of this location, and likely are insignificant to the Meadow Village aquifer.

Land Surface Elevation Figure 2-15 presents land surface data prepared in Digital Elevation Model (DEM) format by the USGS. Elevations are provided in units of meters and are located onto a 30-meter grid spacing. These data were downloaded from the state of Montana Natural Resources Information System (NRIS) website.

Formation Thickness Figure 2-16 presents the interpreted formation thickness of the combined Qal and Qg deposits. This map was created by contouring data obtained from well logs. The locations of the data values are shown on the figure. In general, these data are of poor quality, as many driller's fail to properly distinguish samples of bedrock from unconsolidated gravel. Data obtained from MV #1 to MV #3 are the most accurate and indicate 50 to 67 feet of formation thickness at these locations. Formation thickness thins toward the mapped geological contact, as the Qg and Qal deposits overlie till and bedrock formations.

Groundwater Potential Surface Figure 2-17 presents the interpreted groundwater potential surface, as prepared by Baldwin (1997) based on water level measurements in wells during June 1995. In the Meadow Village area this surface is the water table, and it can be used to infer changes in aquifer transmissivity, as shown by changes in hydraulic gradient. In general, water table contours do not appear to indicate substantial changes in aquifer transmissivity. The gradient is moderately uniform at 0.014 ft/ft in the Meadow Village area. It steepens slightly toward the east, however, this change may be attributed to greater flow occurring in this area. It also is steeper to the southwest, up the South Fork drainage. In this area, the unconsolidated deposits are actually dry, and the contours reflect the hydraulic gradient in bedrock formations. Generally, the water table map does not provide an indication of varying transmissivity that can be used to assist model setup. This finding is not intended to imply, however, that transmissivity does not change throughout the Meadow Village area.

Transmissivity Figures 2-18 and 2-19 present estimated hydraulic transmissivity for bedrock and terrace gravel (Qg) formations. These data were obtained from consultant reports or were computed based on driller's logs. The data are sparse and the quality is generally poor. Values obtained for HV #1 and MV #1 to MV #3 are considered to be the most accurate. Overall these data do not provide a good basis for prediction of transmissivity throughout the model area due to few data points and questionable quality.

Infiltration Recharge The rate at which snowmelt and rainfall penetrate the soils and recharge groundwater was based on the monthly water balance method as applied to the Big Sky 3S data (Table 3-2, Appendix D).

Stream Flow Stream flow measurements for the Meadow Village area were obtained for July 1995 from Baldwin (1997). Measurement stations and the stream reaches to which these data apply are shown on Figure 2-20. The data are summarized in Table 2-5, which also includes a leakage value pertaining to the loss or gain of water in the stream, and therefore the discharge to groundwater or recharge from groundwater that has occurred between the measurement stations. These data show that groundwater recharge occurs from the channel above Station 8 and groundwater discharge occurs to the channel below Station 8. The most significant recharge to groundwater occurs between Stations 2+5 and Station 6. Groundwater discharge occurring to the channel below Station 8 is nearly double to that lost from the channel above Station 8.

TABLE 2-5
WEST FORK STREAM FLOW MEASUREMENTS, JULY 24 – 27, 1995

Sampling Station	Stream Reach	Measured Flow (cfs)	Leakage (m^3/d)[1]
2 + 5	--	42.9	--
6	1	39.3	8,814 (Sta 2+5 - Sta 6)
7	2	38.2	2,693 (Sta 6 – Sta 7)
8	3	37.2	2,448 (Sta 7 – Sta 8)
9	4	49.7	-30,606 (Sta 8 - Sta 9)

[1] Indicates the rate of flow from stream channel to groundwater (positive) or from groundwater to stream channel (negative).

Well Pumping Rates Only MV #1 through MV #5 were represented in the model as pumping wells, which is reasonable because most or all of Meadow Village is supplied by these sources. Production rate data for these wells was obtained from District records and based on estimated maximum production rates, as presented in the District's Water Facility Plan (Allied 2001). These data are summarized in Table 2-6.

TABLE 2-6
MEADOW VILLAGE WELL PUMPING RATES

Well Name	Present Capacity (gpm)	May – June 1995 Average Capacity (gpm)	Future Maximum Capacity (gpm)
MV #1	180	154	400
MV #2	180	134	380
MV #3	230	11	375
MV #4	--	--	350
MV #5	--	--	350

Wells MV #4 and MV #5 are planned wells that will be installed in the future.

Calibration Data

Model calibration was based on field measurements of stream flow and groundwater hydraulic head[22]. Figure 2-20 illustrates the locations of calibration data used in the modeling effort. Stream flow measurements were those obtained by Baldwin (1997) during July 1995, as reported in Table 2-5. Hydraulic head data were obtained for June 1995 from well logs and from the mapping of Baldwin (1997) that is shown on Figure 2-17. Hydraulic head calibration points obtained from Figure 2-17 were selected to provide general coverage of the model area.

[22]Model calibration refers to the adjustment of model parameters as a means to "fit" the model output to actual field observations.

Overall, the calibration data set provides 21 hydraulic head measurements and stream flow for four reaches of the West Fork channel. Stream flow data could have associated error on the order of ±25%. Hydraulic head values could have associated error on the order of ±5 feet. It is also noteworthy that the data apply to the early summer period, which is characterized by high groundwater levels and high stream flow in comparison to average.

Model Setup

MODFLOW requires a data grid that extends over the entire model domain, as shown on Figure 2-21. Calculations of groundwater flow by the model are made based on each grid cell, with model data located at the center of the cell. The initial grid cell spacing was 50- by 50-meters, and was refined in the area of MV #1 to MV #5 to 25- by 25-meters. A total of 57 rows and 110 columns form the grid.

Layers The model includes three layers, numbered 1 to 3 from top to bottom. Layers 1 and 2 represent the Meadow Village aquifer, and are both 10-meters in thickness. Layer 1 was defined as unconfined and Layer 2 was defined as confined. Layer 3 represents bedrock formations that underlie the Meadow Village aquifer, and it was defined as confined. The top elevation of Layer 1 was based on the USGS DEM data. The elevations of the layer interfaces (1 – 2, 2 – 3, and bottom of 3) were also developed from the USGS DEM data by subtracting the layer thickness.

Boundary Conditions There are four boundaries included in the model: 1) infiltration recharge through the top surface, or water table; 2) river cells that occur in Layers 1 and 2, representing leakage to and from the West Fork channel; 3) no flow, or inactive cells, that surround the model and provide horizontal boundaries; and 4) constant head cells that occur throughout Layer 3, providing for discharge from bedrock formations into the Meadow Village aquifer.

- Infiltration Recharge was defined as 16 in/yr for model calibration, representing the high recharge rate that occurs during May and June. This high rate was used to correspond to the stream flow and hydraulic head calibration data.

- River cells were defined based on USGS DEM data for elevation, and assuming a 1-meter stage height in the channel. The river bed conductance parameter was manually adjusted during model calibration. Only the West Fork channel was represented. Crail Creek is apparently dry although it is mapped. The South Fork channel flows primarily over bedrock formations.

- Inactive cells were used to “blank-out” the model grid at all locations outside of the saturated unconsolidated deposits. These cells are used because MODFLOW requires a rectangular grid, and parts of this grid extend beyond the aquifer. It was assumed that horizontal flow from till and bedrock into the Meadow Village aquifer was negligible and did not require representation in the model.

- Constant head cells were defined for all cells in Layer 3 (excluding inactive cells). Layer 3 was not setup to actually represent the bedrock formations explicitly, but only to provide for discharge from bedrock into the Meadow Village aquifer. The head value assigned to constant head cells of Layer 3 was set equal to land surface elevation, as obtained from USGS DEM data. Because the Meadow Village aquifer computed hydraulic head is below land surface, the constant head cells of Layer 3 are always discharging into the aquifer. The vertical hydraulic conductivity of Layer 3 was manually adjusted during calibration to control the rate of discharge from the constant head cells. A value of 0.015 m/d was finally used in the calibrated models.

Hydraulic Conductivity Because the delineation modeling is conducted for steady-state conditions, hydraulic conductivity is the only aquifer property that is required. Two models were developed in order to explore the aquifer response that may be encountered under different but reasonable spatial distributions for hydraulic conductivity. The two models provide a sensitivity analysis for delineation of source water protection areas. In both Models 1 and 2, hydraulic conductivity values were obtained through calibration using WinPEST (see below).

In Model 1, one value of hydraulic conductivity was assigned to Layers 1 and 2 over the entire model domain. There was no spatial variation in hydraulic conductivity within Layers 1 and 2, and no horizontal anisotropy (Kx = Ky), however the vertical anisotropy ratio was 10 (Kx = 10Kz). In Model 2, hydraulic conductivity was varied in three zones, which are shown on Figure 2-22, and were assigned to both Layers 1 and 2. Anisotropy of hydraulic conductivity was handled as for Model 1. The zone boundaries are arbitrary and were included to evaluate if WinPEST would assign significantly different values of K, thus providing insight to a possible spatial distribution of hydraulic conductivity.

Pumping Wells Water supply wells MV #1 through MV #5 were entered as pumping wells in the model, at the locations shown on Figure 2-21. The screen intervals of the wells were defined in Layer 2. To calibrate the model, pumping was entered at the rates shown for May and June 1995 (Table 2-6). For delineation of source water protection areas, the maximum future pumping rates were assigned.

Model Calibration

WinPEST as implemented in Visual Modflow provides for calibration of recharge rate, hydraulic conductivity, and storativity. It cannot presently be used for calibration of river conductance, or other parameters that could be manipulated during a calibration effort. In this application, WinPEST was used to calibrate only hydraulic conductivity in Layers 1 and 2 based on hydraulic head data. River conductance was calibrated by the traditional manual method of model calibration based on stream flow data presented in Table 2-5. This approach is not ideal, but is vastly improved over the completely manual methods. Appendix E provides the WinPEST run record file output that was obtained from the final calibration run of both Models 1 and 2.

Figures 2-23 and 2-24 present hydraulic head calibration plots for Models 1 and 2, respectively. Both models achieved equal levels of calibration, and appear to be slightly biased with the model hydraulic head greater than the field data hydraulic head. The standard deviation of the calibration residual (model – observed) was 0.4 to 0.5 m. The average residual, or root mean squared error, was 2.1 m and 2.5 m.

Calibration to stream flow data are shown in Table 2-7. These results indicate that overall the model water balance was satisfactory, but that leakage rates by reach deviated significantly from the field measurements. In completing the modeling work, it appeared that more data are needed to characterize the aquifer hydraulic conductivity in order to improve the calibration to stream flow measurements.

TABLE 2-7
CALIBRATION TO STREAM FLOW DATA

	Model 1 (m^3/d)			Model 2 (m^3/d)		
Stream Reach	Model	Observed	Residual	Model	Observed	Residual
Reach 1	11000	8,814	2,186	8800	8,814	-14
Reach 2	3041	2,693	348	5825	2,693	3,132
Reach 3	-2823	2,448	-5,271	70	2,448	-2,378
Reach 4	-27675	-30,606	2,931	-31221	-30,606	-615
		Residual Sum	194		Residual Sum	125

Calibration parameters are presented in Table 2-8 for each model. WinPEST output provides estimated 95% confidence intervals for the hydraulic conductivity parameters, which are reported. In general, these confidence intervals are wide where parameter correlation does not enable good resolution of the parameter. The objective function determined by WinPEST for each model is also shown in Table 2-7. This function indicates the overall fit of the model to the calibration data, and as shown, Model 2 produces a better fit than Model 1. This better fit is attributed to the greater flexibility allowed in Model 2 by the three zones of varying conductivity. In general, the calibrated parameter values are reasonable estimates for actual values. It is an interesting result that Zone 4 conductivity in Model 2 appears to be significantly greater than for Zones 2 and 3. This result suggests, but is not conclusive, that hydraulic conductivity in the eastern part of Meadow Village aquifer may be increased relative to the west. The existing well log data, which are of questionable quality, generally do not support this finding.

Model output of the water balance is also provided and useful for determining model performance. Water balance data are presented in Table 2-9 for both Models 1 and 2, and for the delineation mapping runs, which are discussed below. The results are presented in terms of three common volumetric flow rate units. The in – out water balance was accurate to within less than 0.00% for all model runs.

TABLE 2-8
PARAMETER ESTIMATES FROM CALIBRATION

Parameters	Model 1			
	Estimate	Lower Limit	Upper Limit	Objective Function
Kx2 (m/d) (Kx = Ky = 10Kz)	86	72	103	121.9
	Reach 1	Reach 2	Reach 3	Reach 4
River Conductance (m^2/d)	400	100	100	600
	Model 2			
	Estimate	Lower Limit	Upper Limit	Objective Function
Kx2 (m/d) (Kx = Ky = 10Kz)	73	44	122	77.9
Kx3 (m/d) (Kx = Ky = 10Kz)	64	52	78	
Kx4 (m/d) (Kx = Ky = 10Kz)	146	95	225	
	Reach 1	Reach 2	Reach 3	Reach 4
River Conductance (m^2/d)	500	100	100	600
Hydraulic conductivity was estimated for the Kx value only in each zone. It was assumed that Kx equal Ky (anisotropy ratio = 1) and that Kx divided by Kz equal 10 (anisotropy ratio = 10). These relations were established in WinPEST using the "tied to" option and the initial parameter values. River conductance values were calibrated manually.				

Figures 2-25 and 2-26 present output for Layers 1 and 2 of model calculated hydraulic head for Model 1 (results are very similar for Model 2 and are not shown). As shown on Figure 2-25 for Layer 1, many of the model cells became dry indicating the saturated thickness of the aquifer existed only in Layer 2 at these locations. Layer 2 below dry cells also is partially saturated, however, the model does not correct transmissivity in these cells for partial saturation (Layer 2 was specified as a confined layer type). This correction should be considered during future applications of the model. Overall, the results are considered a reasonable representation of the Meadow Village aquifer.

Delineation

MODPATH is the companion program to MODFLOW that is used for calculating groundwater pathlines, and therefore, the delineation areas of water supply wells. MODPATH was run for both Models 1 and 2 to generate pathlines based on groundwater travel time. These pathlines were used to construct the Inventory Region and Recharge Area for MV #1 through MV #5, as presented above.

Prior to running MODPATH, the MODFLOW Models 1 and 2 were altered to represent more average dryer conditions in the Meadow Village aquifer, and the pumping rates of the wells were set to the future maximum rates (Table 2-6). Moderately extreme conditions were simulated in order to develop a conservative estimate of the capture zones for the wells.

The dryer conditions were represented by lowering river stage height by 1-foot, by eliminating infiltration recharge, and by reducing the contribution of flow from bedrock formations. The water balance data for the adjusted models are shown in Table 2-9. Values presented in Table 2-8 show an increase in the recharge from bedrock formations. This additional recharge is actually induced from the large pumping rates of MV #1 through MV #5. When the models were first adjusted under low pumping conditions, bedrock formation recharge was reduced to about 13,700 m^3/d by adjusting the Layer 3 vertical hydraulic conductivity to a value of 0.0085 m/d. This lower value of vertical hydraulic conductivity was used in the delineation modeling.

Figures 2-27 and 2-28 show the pathline output for both models. Little difference exists in overall area occupied by pathlines, and slight differences exist in terms of travel time. Model 2 produced a larger pathline area and longer travel times in comparison to Model 1. Twenty-five particles were released for upstream tracking from each well. Particles were released along a 25-meter radius circle in Layer 2 of the model. Pathline arrowheads are drawn with a 30.42-day increment (average month). Pathline output shows the recharge area for MV #1 to MV #5 is relatively small in area and largely dependent on discharges to groundwater from surface streams. Travel time from recharge area to well ranges from about 5- to 11-months. The Inventory Region and the Recharge Area boundaries coincide because total groundwater travel time is less than the 3-year criterion used to define the Inventory Region.

2.6 Management Areas

Inventory Regions and Recharge Areas developed in the preceding sections have been lumped into management areas that are presented on Figures 2-29 and 2-30. The purpose of management areas in this application is to simplify the geometry of source water protection areas. Management areas are also defined to generally cover more area than was delineated, providing a factor of safety for uncertainty related to hydrogeological and mapping data.

Figure 2-29 shows three Inventory Region Management Areas pertaining to Mountain Village, Lone Moose Meadows, and Meadow Village. These areas are drawn to include and extend beyond the delineated Inventory Region for each well, and to conform to ¼¼-section township-range designations[23]. Contaminant source inventory data collection and risk management pertaining to specific contaminants are applied in the Inventory Region Management Area.

Figure 2-30 presents a Recharge Management Area that encompasses the entire Big Sky watershed. This area includes delineated Recharge Areas for the wells of this report. Management in this area is intended to focus on large developments, such as mining or major subdivisions, or significant land use planning, such as National Forest Management Plans. The District will not regularly survey or inventory this area, but should review large projects for potential impacts to water resources in the Big Sky area.

[23]The delineated Inventory Region for Hidden Village No. 2 (SW Sec. 35 6S3E) does not lie completely within the Inventory Region Management Area. The small part of the delineated Inventory Region that is not included is located on the down-gradient side of the well and actually is outside of the true recharge area to the well.

TABLE 2-9
MODEL WATER BALANCE OUTPUT

Units – m^3/d				
Parameter	Model 1		Model 2	
	Calibration	Delineation	Calibration	Delineation
River Leakage				
Reach 1	11000	7370	8800	5895
Reach 2	3041	1943	5825	870
Reach 3	-2823	304	70	737
Reach 4	-27675	-17098	-31221	-16321
Infiltration Recharge	4072	0	4072	0
Bedrock Formations	14015	17594	14086	18930
Pumping Wells	-1630	-10113	-1630	-10113
Units – gpm				
Parameter	Model 1		Model 2	
	Calibration	Delineation	Calibration	Delineation
River Leakage				
Reach 1	2016	1351	1613	1081
Reach 2	557	356	1068	159
Reach 3	-517	56	13	135
Reach 4	-5073	-3134	-5723	-2992
Infiltration Recharge	746	0	746	0
Bedrock Formations	2569	3225	2582	3470
Pumping Wells	-299	-1854	-299	-1854
Units – cfs				
Parameter	Model 1		Model 2	
	Calibration	Delineation	Calibration	Delineation
River Leakage				
Reach 1	4.49	3.01	3.59	2.41
Reach 2	1.24	0.79	2.38	0.36
Reach 3	-1.15	0.12	0.03	0.30
Reach 4	-11.30	-6.98	-12.75	-6.67
Infiltration Recharge	1.66	0.00	1.66	0.00
Bedrock Formations	5.72	7.19	5.75	7.73
Pumping Wells	-0.67	-4.13	-0.67	-4.13
A positive value indicates flow into the model domain. A negative value indicates flow out of the model domain.				

3 INVENTORY

This section describes the potential contaminant sources that occur within the Source Water Protection Areas for the District, including the Control Zone, Inventory Region Management Area, Recharge Area Management Area, and the Surface Water Buffer. These potential contaminant sources were identified by review of existing maps, searching of state and federal databases, and a field survey of the area.

3.1 Land Use

A review of land uses provides a general overview of groundwater contamination potential. Typically groundwater contamination will be associated with high density urban and heavy industrial land uses. Significant contamination has also occurred in association with light manufacturing and small commercial properties.

Big Sky is an area of residential living and recreation without the common services and industries of larger towns and cities. The largest commercial area is located at the junction of the Big Sky Spur Road and Highway 191, about 2 miles east of Meadow Village and outside of the Source Water Protection Areas. Most of the lower elevation areas in the valleys are residential or yet to be developed for residential uses of moderate density. Above and outside the valleys, the area is open-private or open-public land. A designated Wilderness Area also exists to the north of Big Sky.

Land use information for the Big Sky area, primarily within the Inventory Region Management Areas, is shown on Figures 3-1 and 3-2. Both maps are parcel maps obtained from the District and illustrate the various levels of subdivision in Big Sky[24]. The vast majority of the land area is undeveloped open land. The next most abundant land uses are residential and recreational. Small parcels correspond primarily to single family and multi-family (condominiums) dwellings. Some small parcels also correspond to commercial land uses, located in both Meadow Village and Mountain Village, although overall, little of the Big Sky area is presently in commercial use. The large acreage tracts in proximity to the Meadow Village wells (Figure 3-1) are the Big Sky golf course. Otherwise, large acreage tracts correspond to single homes or undeveloped lands. Lands outside the parcel mapping area are also outside the District service area. These lands are primarily open private and public lands with sparse development.

Timber harvest is conducted on a limited number of large parcels and perhaps public lands in the area. When touring the area, however, there is no indication that large-scale logging operations are in action, at least in immediate proximity to Meadow- and Mountain-Village. Harvesting of trees appears to occur primarily on private lands prior to subdivision development.

Under present conditions, the most abundant groundwater contaminant associated with the Big Sky area land uses is domestic wastewater, a source of nitrate and pathogens. Discharge of treated wastewater to groundwater, either by centralized treatment plants or from high densities of septic systems, will be the most likely mechanism for degradation of groundwater quality.

3.2 Septic System Hazard

Septic systems used for on-site wastewater discharge can be a source of nitrate and pathogen contamination in groundwater. Septic system density was evaluated within the Source Water Protection

[24] Land use mapping by the USGS and that is available from the NRIS website was reviewed. These data indicated a single Open land use for the entire Big Sky area. Consequently, it was concluded the mapping information was not current, and for this reason is not displayed in the SWDAR.

Areas based on population. This indirect method of estimating septic density is used in the absence of detailed septic system location maps. Figure 3-3 presents a map of estimated septic hazard based on population with an overlay of the sewer service area. As shown, the highest population density, which would correspond to moderate and high septic hazard, is predominantly served by sewers[25]. Consequently, actual septic density is low in the Source Water Protection Areas, and the associated septic hazard to the wells of this report also is considered low. Septic systems are not considered a significant source of contamination in the Big Sky area.

3.3 Existing Wells

Existing wells with poor construction and no longer in use may increase the risk of contamination to deep confined aquifers. Such wells can act as vertical conduits, allowing contaminants in shallow groundwater to migrate via the well below natural barriers. Figure 3-4 presents a map of existing wells located in the area and recorded in the Ground Water Information Center (GWIC) database. The GWIC well locations shown have a reported total depth exceeding 200 feet. These results indicate few deep wells are located within 1,000-ft of the confined wells. The density of existing wells ranges from 0 to about 14 wells per square mile. There are no existing wells greater than 200 feet deep within 1,000 feet of the Blue Grouse (BG) well. Mountain Village No. 4, Hidden Village No. 2 and the Lone Moose wells each have one existing well inside the Inventory Region. There are two existing wells located inside the Inventory Region of the Aspen Grove wells.

3.4 Point Sources

Point sources of groundwater contamination include a wide array of possibilities. The classic example of a point source is a leaking underground gasoline storage tank. Other types of point sources may include a landfill, a dry cleaner's septic system, an above ground bulk chemical storage facility, and a mine.

Point sources were identified by database review and by a field survey. The field survey appeared to be a more effective means for identifying potential point sources. Database searching included the MDEQ Source Water Protection Program website query program. Each data type corresponding to a potential contaminant source was reviewed within a 3-mile radius of the Mountain Village and Meadow Village water systems. The U.S. EPA Envirofacts database was also searched for hazardous waste generators and handlers based on the Big Sky postal code, 59716. The categories of contaminant sources that were reviewed include the following:

- Montana Comprehensive Environmental Cleanup Sites
- EPA CERCLIS Sites
- EPA Toxic Release Inventory
- Landfills (Active, Inactive)
- Underground Storage Tanks (Active, Inactive, Leaking)
- Mines, abandoned and existing
- Stormwater and Wastewater Discharges
- RV Dump Sites
- Crude Oil Pipelines
- Hazardous Spill Sites

[25] Septic density is based on the 2000 census block data obtained from NRIS. A septic system is assigned to each 2.6 persons. The density is obtained in units of septic systems per square mile, and assigned as follows: <50 – low; 51 to 130 – moderate; and >130 – high.

- Railroads
- Confined Animal Feeding Areas

TABLE 3-1
POINT SOURCES

Map ID	Location	Description	Significant Source[1]
1	Mountain Village	Power or phone facility	No
2	Mountain Village	Hotel mechanical building	No
3	Mountain Village	Hotel maintenance facility	No
4	Mountain Village	Ski area maintenance shop (UST/AST?)	Yes
5	Mountain Village	Ski area maintenance shop disposal area	Yes
6	Mountain Village	Power of phone facility	No
7	Mountain Village	Fire station	No
8	Mountain Village	Power substation	No
9	Lone Moose	Dumpster site	No
10	Lone Moose	Stormwater culvert discharge	Yes
11	Lone Moose	Ski lift generator	No
12	Lone Mountain Ranch	Horse pen-up and feed area	Yes
13	Lone Mountain Ranch	Maintenance facility (2 AST)	Yes
14	Meadow Village	Nursery	No
15	Meadow Village	Self-serve laundry	No
16	Meadow Village	Golf course maintenance shop (2 AST)	Yes

[1]Significant sources are included in the Susceptibility Assessment of Section 4.
UST – underground storage tank; AST – above ground storage tank.

3.4.1 Field Survey

Table 3-1 provides a listing of potential contaminant sources identified from the field survey. The locations of these sources are shown on Figures 3-5 and 3-6. Each source listed in Table 3-1 has been identified as significant or insignificant in the last column. Most of the potential sources listed in Table 3-1 likely are not of significant risk to cause groundwater contamination. They are listed here because they are among the few commercial activities that may involve chemical use and storage, and are located in the Inventory Region Management Areas. At several of the listed sites, it is possible that chemical handling does not occur, or that only small quantities of less than 50 gallons are handled or stored.

The ski area maintenance shop (#4) and its related disposal area (#5) may be a potential source of groundwater contamination. This facility is up-gradient 1,000 to 2,000 feet from Mountain Village Well Nos. 1, 2, 3 and 4. It is expected this facility handles oil and anti-freeze regularly, and may be a storage site for fuel used to operate the snow grooming equipment[26]. The disposal area presently includes approximately 10 used chemical drums. Overall, the facility appears poorly kept.

[26] Presumably there is bulk fuel storage at the ski area for this equipment, however, the tanks were not located in completing the contaminant source inventory, either by field survey or from database searching.

A stormwater culvert discharge (#10) located within about 50 feet of Lone Moose No. 2 is considered a potential contaminant source for this well. The discharge floods the area of the well, and the well is presently not properly landscaped to divert surface water runoff away from the casing.

A horse pen-up area (#12) located on Lone Mountain Ranch appears to be a potential contaminant source for Hidden Village No. 1. This area is about 1 to 2 acres and was occupied by about 50 horses when observed. It is a low density confined animal feeding area and the ground surface is bare of vegetation. High recharge and runoff from the facility could result in a nitrate and pathogen loading to groundwater 200 to 500 feet up-gradient from the well. The District has constructed earthen berms to divert surface water runoff away from the well and booster station.

The Lone Mountain Ranch (#13) maintenance facility also appears to be a potential contaminant source for Hidden Village No. 1. This facility is the site of above ground fuel storage, including a 1,000 gallon gasoline tank and 500 gallon diesel tank. There are also small containers of fuel, oil and chemicals in storage at this facility.

The Golf Course maintenance facility (#16) is considered a potential contaminant source, and is located up-gradient from Meadow Village Well Nos. 1, 2 and 3, and future well sites MV-4 and MV-5. There are two above ground storage tanks located at this facility, each of 1,000 gallons and used for gasoline and diesel fuels. Both tanks are recently new combination steel and concrete lined, and can be easily monitored for leaking conditions. The facility also handles small quantities of oil and antifreeze related to mowing equipment maintenance. Hazardous fluids are removed from the site, and the facility is connected to the sanitary sewer.

3.4.2 Database Search

Several sources were identified by database searching but could not be field confirmed, or were located outside the Source Water Protection Areas. One of the most abundant source types was related to historic mining activities in the area. Three to four exploration sites or small extraction locations were identified within the Recharge Area MA in the mountainous uplands to the north of Big Sky. These sites were not visited, but most likely consist of shallow excavations or shafts used for exploration purposes, and are considered to pose minimal risk for the wells of this report. There are no abandoned or active mine sites that have been identified in the Recharge Area.

3.5 Spray Irrigation

The District conducts unrestricted spray irrigation of treated wastewater effluent on the Big Sky Golf Course. This irrigation is in the vicinity of Meadow Village Well Nos. 1, 2 and 3, and the future well sites of Meadow Village Well Nos. 4 and 5. Spray irrigation water may contain high concentrations of nitrate and pathogens in the event of treatment and/or monitoring failure, and consequently, is considered a potential source of groundwater contamination.

The approximate area where spray irrigation occurs is shown on Figure 3-6. Unrestricted spray irrigation is allowed according to MDEQ Circular DEQ-2 for this system. Water quality criteria require that the 7-day median coliform concentration be less than 2.2 cfu/100 mL, and that the maximum coliform concentration be less than 23 cfu/100 mL. Spray irrigation also cannot occur within 100-feet of water supply wells. The system is operated in compliance with these standards.
Wastewater treatment consists of aerobic and anaerobic degradation in a lagoon system followed by disinfection, filtration and disinfection with contact time. Treated effluent is initially discharged into a lined reservoir, and is then pumped to the irrigation distribution system. The spray irrigation system is operated such that applied irrigation water will be evapotranspired, rather than recharge groundwater.

The District monitors groundwater in six monitoring wells, designated as Drill Hole Nos. 1 to 6, however, Drill Hole No. 3 is always dry. Monitoring of vadose zone water quality and groundwater recharge is also conducted in six weighing lysimeters, designated as Lysimeters Nos. 1 to 6. The locations of these monitoring points are shown on Figure 3-6, and historic data collected since 1997 is provided in Appendix F.

3.6 Sanitary Sewer

Sanitary sewer leaks can result in contamination of groundwater by nitrate and pathogens. The District operates a sanitary sewer system that is located within the Source Water Protection Areas, and consequently, is considered a potential source of contamination to the water supply wells. Figures 3-5 and 3-6 include mapping of the sanitary sewer system in the Mountain Village and Meadow Village areas.

Sanitary sewers appear to be within 100-feet of Mountain Village Nos. 1, 2, 3, and 6, the Blue Grouse well, Hidden Village No. 2, and Meadow Village No. 1. These well locations do not meet set back requirements that would apply to new wells per MDEQ Circular DEQ-1.

Two larger diameter sewer lines run along Little Coyote Road, immediately north of Meadow Village Nos. 1, 2 and 3, and within an easement along Curley Bear Road and Black Otter Road to the south. The sewers in these two areas are conveying relatively large wastewater flows to the treatment plant, which is located on Figure 3-6.

4 SUSCEPTIBILITY ASSESSMENT

The state of Montana has developed a method to determine the susceptibility of a well to be contaminated by a given potential source of contamination. The susceptibility categories that may be assigned include very-low, low, moderate, high, and very-high. Very low susceptibility indicates that a potential contaminant source has less likelihood of impacting a well in comparison to a source with a designated very-high susceptibility. The actual risk, as a quantified probability to contaminate the well, is not determined by this method. The method results are qualitative and are intended for use in prioritizing management activities.

4.1 Method Summary

Susceptibility assignments (to a well) are made for each significant potential contaminant source identified in the source inventory, including point and non-point sources. The method is conservative, resulting in generally high susceptibilities even when a quantified risk of contamination may be very low. Some of the conservative nature of the method is eliminated by only applying the method to significant potential sources of contamination. Significant potential contaminant sources that are normally considered in a susceptibility assessment include the following:

- Septic systems
- Animal feeding operations
- Underground storage tanks
- Leaking underground storage tanks
- State and federal superfund sites
- RCRA large quantity generators
- Underground injection wells
- Wastewater treatment / spray irrigation / lagoons
- Landfills
- Abandoned mines
- MPDES wastewater discharges
- Municipal sanitary sewers
- Municipal storm sewers
- Storm water discharges
- Highways, railroads and pipelines
- Cultivated cropland

There are two steps to determining susceptibility. First, the potential contaminant source is assigned a hazard level, based simply on its occurrence within a source water protection area. Hazard levels are categorized as low, moderate, and high. Those sources that are nearest to a source water intake (or occupy a large land area) will have a higher hazard classification than sources that are farther away (or occupy a small land area).

In step two, the occurrence of barriers, either natural or engineered, that may protect the water source intake from the potential contaminant source are evaluated. An upward groundwater flow direction and/or a low permeability clay layer above an aquifer are types of natural barriers. Properly constructed wells and wells with deep seals into confining layers are examples of engineered barriers. If there are no barriers then little protection exists to prevent contamination of water in the event of a spill or leak. If one or more barriers are present, a spill or leak is likely to be captured or impeded.

Once the hazard level and number of barriers has been determined for each significant contaminant source, a susceptibility level can be designated. Table 4-1 summarizes the susceptibility categories with respect to the hazard level and the existence of barriers.

TABLE 4-1
SUSCEPTIBILITY CATEGORIES

Presence of Barriers	Hazard Level		
	High	Moderate	Low
No Barriers	Very High	High	Moderate
One Barrier	High	Moderate	Low
Multiple Barriers	Moderate	Low	Very Low

Table entries are the susceptibility (to be contaminated) of a water source intake to a specified potential contaminant source. The susceptibility level is determined based on the hazard level of the potential contaminant source and the number of barriers that exist to protect the water source from contamination.

4.2 Natural and Engineered Barriers

Natural and engineered barriers reduce the risk of contaminants migrating to a water supply well. Barriers may be assigned based on natural conditions or engineered systems related to the well. Table 4-2 provides a listing of barriers pertaining to the project wells where barriers exist. Three types of barriers were identified for selected wells. Compliance with the state of Montana water well construction rules is considered an engineered barrier. Wells with a documented grout surface seal equal to or greater than 18-feet in depth fulfill this criteria. An additional engineered barrier was assigned for wells with a surface seal exceeding a depth of 100-feet and extending into a confining formation. Upward groundwater flow, as evidenced by artesian conditions, was identified as a natural barrier for Hidden Village No. 2 and the Blue Grouse well. There are no barriers, either natural or engineered, that can be assigned to wells not listed in Table 4-2.

TABLE 4-2
BARRIER ASSIGNMENTS

Well Name	Barrier No. and Type	Description
MV-3, MV-4, MV-5, HV-1, HV-2, BG, AG-1, AG-2, AG-3, LM-1, LM-2, MTN-4, MTN-5, MTN-6	1 – Engineered	Wells are constructed in compliance with state of Montana water well construction rules. HV-1 is further protected from surface water runoff by earthen berms uphill from wellhead.
HV-2, BG, MTN-5	1 – Engineered	Well seal extends greater than 100 feet into confining layers.
HV-2, BG	1 – Natural	Upward groundwater flow occurs at well.

4.3 Source Water Susceptibilities

Susceptibility designations are provided for each significant potential contaminant source and with respect to individual wells in Table 4-3. In general, the susceptibility designations appear to be reasonable with two exceptions, as follows:

- Point source #16 is the Golf Course maintenance shop. It appears the susceptibility designations are too high in relation to this source. Based on review of the facility, Moderate designations are more appropriate. Fuel tanks at this facility are above ground on a concrete slab and easily monitored. Waste oil is recycled for use in oil-burning heaters. Other chemicals are stored in small quantity, and the facility is served by the sanitary sewer.

- Susceptibility designations related to spray irrigation appear too high for the Meadow Village wells. A susceptibility of Moderate seems reasonable for this source, particularly given the treatment process, full-time operations staff, and regular monitoring of the effluent quality.

Conditions that are noteworthy and which received high susceptibility designations include the following:

- Point source #10 is a stormwater discharge culvert located near to Lone Moose No. 2. This discharge may be a substantial threat to water quality produced from this well, which has only a 20-foot surface seal. The discharge should be properly routed to pass the well without infiltration potential, such as in a culvert or lined swale.

- Point source #12 is the horse pen-up/feed lot area adjacent to Hidden Village No. 1. This source is primarily of concern during spring when runoff and recharge are occurring. It is desirable for the District to negotiate with Lone Mountain Ranch to move this area farther from the well.

- Sanitary sewers resulted in High and Moderate susceptibility designations for most of the wells. These designations appear reasonable considering the proximity of sewers to wells located at Mountain Village and the larger sewer lines that occur to the north and south of the Meadow Village aquifer.

TABLE 4-3
SUSCEPTIBILITY DESIGNATIONS

Source Type	Contaminants	Contaminants Origin	Well Name	Hazard Rating	No. Barriers	Susceptibility
Point Source #4, #5	VOCs, SOCs, IOCs	Spill or Leak	MTN-1,2,3	Moderate	0	High
			MTN-4	Low	1	Low
Point Source #10	Nitrate, pathogens	Flooding at wellhead	LM-2	High	1	High
Point Source #12	Nitrate, pathogens	Recharge, runoff	HV-1	High	1	High
Point Source #13	VOCs, SOCs	Spill or Leak	HV-1	Moderate	1	Moderate
Point Source #16	VOCs, SOCs	Spill or Leak	MV-1, 2	High	0	Very High
			MV-3, 4, 5	High	1	High
Spray Irrigation	Nitrate, pathogens	Treatment or monitoring failure	MV-1, 2	High	0	Very High
			MV-3, 4, 5	High	1	High
Sanitary Sewer	Nitrate, pathogens	Leak	MV-1, 2	Moderate	0	High
			HV-2, BG, MTN-5	Moderate	3	Low
			All Others	Moderate	1	Moderate
VOC, SOC, and IOC indicate volatile organic compounds, synthetic organic compounds, and inorganic compounds, respectively.						

5 AQUIFER VULNERABILITY

Work completed by Baldwin (1997) as a master's thesis included vulnerability mapping of groundwater in the Meadow Village area. Given the relevance of this mapping to Source Water Protection, total vulnerability, as mapped by Baldwin (1997), is shown on Figure 5-1. This map was created from an Arc View shape file (total.shp) provided to the District by the author. It is similar by not exactly the same map as was originally presented (Baldwin 1997, Figure 20).

Vulnerability is a concept that indicates the ability for contaminants to migrate to groundwater from surface releases. Land surface areas are classified as low, moderate or high vulnerability based on a numeric score considering factors such as soil type, depth to groundwater, and geological formations. Migration of contaminants to groundwater is easier in areas of high vulnerability in comparison to areas of low vulnerability. The map shown on Figure 5-1 considers soil type, depth to groundwater, and surface geology in order to derive a total vulnerability score. The scores ranged from 0 to 12 and were classified into three classes, low to high, as shown in the figure legend.

Figure 5-1 provides useful illustration to show that the Meadow Village area is an area where surface contaminants may more easily migrate to groundwater than in the adjacent hillsides. The vulnerability designation in the Meadow reflects to a large degree geological mapping of alluvial deposits in this area. These deposits are porous unconsolidated mixtures of clay, silt, sand and gravel that do not impede contaminant migration as well as bedrock and clay soils located in the upland areas.

It is noteworthy that ease of infiltration in the Meadow Village area was demonstrated during a pumping test of Meadow Village No. 1 (Western Groundwater Services 1999). Well discharge onto the land surface approximately 100 feet from the wellhead was shown to recharge groundwater within several hours after discharge began. The drawdown data of the test were shown to begin rising due to the recharge that was occurring by infiltration of the well discharge (the test was successfully repeated after routing the discharge farther from the well).

6 RECOMMENDATIONS

Recommendations are provided in this section for guidance purposes only and are completely voluntary on the part of the District. There are no regulatory obligations established by the inclusion of these recommendations in this SWDAR. The recommendations described below are considered to be beneficial to long-term source water protection and source development.

- The District should complete a Source Water Protection Plan (SWPP), using this SWDAR as a technical basis. The purpose of the SWPP is to develop a long-term strategy to protect the water supply sources of this report. There are typically three elements to an SWPP. These include contingency planning in order to respond to temporary water loss conditions; identification of alternative water sources in order to replace a permanently lost water source; and management planning to identify and implement activities that will mitigate risk of water loss. The preparation of an SWPP is a group activity done by committee, although a consultant will normally facilitate the process and provide technical data. Committee members should include District staff, a District Board member, and representation from Gallatin County, citizens, and business interests. The completed SWPP is ultimately approved for implementation by the District Board, and in this case, possibly Gallatin County. One option for the District to explore is to participate in a Gallatin County SWPP that will include other water systems in the county. A joint effort may be more effective at gaining approval at the county level, which could be beneficial for addressing future land use issues. Preparation of an SWPP for the District may result in expenditures of $4,000 to $8,000 depending on the level of participation by committee members.

- This SWDAR can be distributed to local entities in order to immediately begin Source Water Protection efforts. By educating local entities on the locations of Source Water Protection Areas, some level of increased protection should be achieved. Local entities that receive the SWDAR may include, for example, Big Sky Golf Course, the Big Sky Resort Ski Area, Lone Mountain Ranch, Big Sky Fire District, the Gallatin Local Water Quality District and the U.S. Forest Service – Supervisor's Office and local Ranger District. It may be advisable to prepare an abbreviated document providing a short explanation and maps of the Source Water Protection Areas for these distributions.

- Gallatin Local Water Quality District (GLWQD) should be extended to include the District and the Big Sky area. The GLWQD provides public education, water quality and level monitoring, and source inventory data collection, among other activities. The purpose of the GLWQD, to protect and enhance understanding of water resources, is consistent with the intentions of Source Water Protection Planning. Based on discussion with GLWQD staff, there do not appear to be any obvious reasons as to why the boundary cannot be extended to include Big Sky. The District will need to engage in discussion with the GLWQD Board and ultimately, approval is required by the County Commission (the GLWQD is funded in part from county taxes).

- The contaminant source inventory of this report should be updated annually and submitted to MDEQ every 5-years. This work could likely be completed by the GLWQD if the District is successful in extending the boundary to include Big Sky. The next submittal of inventory data to MDEQ should occur during June 2007.

- The Meadow Village Aquifer model developed as part of the SWDAR should be used to evaluate wellfield capacity for future planning of water source development. The Water Facility Plan (Allied 2001) indicates that the existing Meadow Village wells should be increased in capacity and that two new Meadow Village wells will be added at some future time. It is not presently known or estimated, however, as to whether or not the Meadow Village aquifer can sustain the increased pumping. The model developed for this project can be used as a simulation tool to evaluate the feasibility of the planned source development.

- Calibration of the Meadow Village Aquifer model utilized limited data for stream flow and groundwater level. Although these data are effective for model calibration, the present data set is limited in number of measurements. An improved data set will enable more insightful calibration of the model, and ultimately improved understanding of the Meadow Village Aquifer. Assessment of the Meadow Village Aquifer to sustain pumping from the District's wells will benefit from an improved calibration data set. Additional data should be collected consisting of groundwater level measured in monitoring wells and stream flow measurements. The District should begin to record monthly groundwater level in monitoring wells that are used for spray irrigation monitoring. It will be useful, however, to extend the monitoring of these wells through the winter months. If available, it will be beneficial to extend the groundwater level monitoring to a few existing wells located in the west and southwest areas. Stream gauging data for the West Fork West Gallatin River through the Meadow Village area should be considered at up to three locations. This monitoring effort could likely be coordinated with the GLWQD if the boundary is extended to the Big Sky area.

7 REFERENCES

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APPENDIX A

WATER AND SEWER SYSTEM MAPS

APPENDIX B

WELL LOGS

WELL LOGS

CROSS SECTION A-A’

WELL LOGS

CROSS SECTION B-B’

WELL LOGS

CROSS SECTION C-C’

WELL LOGS

CROSS SECTION D-D’

APPENDIX C

2001 CONSUMER CONFIDENCE REPORT

APPENDIX D

GROUNDWATER RECHARGE WATER BALANCE

APPENDIX E

WinPEST RUN RECORD

APPENDIX F

SPRAY IRRIGATION MONITORING DATA

APPENDIX G

SANITARY SURVEY REPORTS