SIMULATION OF CHANGES IN WATER LEVELS AND GROUND-WATER FLOW IN RESPONSE TO WATER-USE ALTERNATIVES IN THE MUD LAKE AREA, EASTERN SNAKE RIVER PLAIN, EASTERN IDAHO

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 93–4228

Prepared in cooperation with the

IDAHO DEPARTMENT OF WATER RESOURCES and U.S. DEPARTMENT OF ENERGY

SIMULATION OF CHANGES IN WATER LEVELS AND GROUND-WATER FLOW IN RESPONSE TO WATER-USE ALTERNATIVES IN THE MUD LAKE AREA, EASTERN SNAKE RIVER PLAIN, EASTERN IDAHO

By JOSEPH M. SPINAZOLA

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 93–4228

Prepared in cooperation with the

IDAHO DEPARTMENT OF WATER RESOURCES and
U.S. DEPARTMENT OF ENERGY

Boise, Idaho
1994

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
ROBERT M. HIRSCH, Acting Director

For additional information write to:

District Chief
U.S. Geological Survey
230 Collins Road
Boise, ID 83702–4520

Copies of this report can be purchased from:

U.S. Geological Survey
Earth Science Information Center
Open-File Reports Section
Box 25286, MS 517
Denver Federal Center
Denver, CO 80225

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic meter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

SIMULATION OF CHANGES IN WATER LEVELS AND GROUND-WATER FLOW IN RESPONSE TO WATER-USE ALTERNATIVES IN THE MUD LAKE AREA, EASTERN SNAKE RIVER PLAIN, EASTERN IDAHO

By Joseph M. Spinazola

ABSTRACT

Water users rely on surface and ground water to irrigate crops and maintain wildlife refuges in the 2,200-square-mile Mud Lake study area. Water managers need the ability to evaluate the effects of water-use changes on the future supply of surface and ground water. A five-layer, three-dimensional, finite-difference, numerical ground-water flow model, calibrated to assumed 1980 steady-state hydrologic conditions, was used to evaluate potential effects of seven water-use alternatives on ground-water levels and on losses from and gains to streams and lakes. The model was used to simulate steady-state water levels and ground-water flow for average 1980–90 hydrologic conditions and for seven water-use alternatives that represented changes from average 1980–90 conditions. Five alternatives represented reduced withdrawals from five different sets of wells, the sixth represented increased withdrawals in areas that could potentially support additional irrigation development, and the seventh represented reduced recharge in part of the study area where change from subirrigation to sprinkler irrigation is taking place. Simulated results from each alternative were compared with results for average 1980–90 conditions.

Among the five water-use alternatives in which withdrawals from wells were reduced, simulated water levels were 0.1 to 40 feet higher than average 1980–90 conditions. Simulated stream and lake losses were as much as 4,700 acre-feet less and simulated gains were as much as 19,000 acre-feet greater in response to simulated water-level rises. Simulated underflow into the study area was as much as 8,200 acre-feet less and simulated underflow out of the study area was as much as 91,000 acre-feet greater. Simulated water-level declines were as great as 15 feet for the sixth alternative (increased withdrawals) and 10 feet for the seventh (reduced recharge). Simulated stream and lake losses were as much as 5,700 acre-feet greater and simulated gains were as much as 37,000 acre-feet less for stream and lake segments due to simulated water-level declines. Simulated underflow into the study area was as much as 7,200 acre-feet greater and simulated underflow out of the study area was as much as 23,000 acre-feet less.

INTRODUCTION

The Mud Lake area covers about 2,200 mi^2 in the northernmost part of the eastern Snake River Plain (fig. 1). Irrigators, wildlife managers, and others in the area depend on an adequate supply of surface and ground water for agriculture, wildlife, and other uses. Most cultivated agricultural land in the area is irrigated with water pumped from wells completed in the eastern Snake River Plain aquifer system. Lakes within the Mud Lake Wildlife Management Area (WMA), Camas National Wildlife Refuge, and Market Lake WMA provide habitat for migratory waterfowl and native flora and fauna. Mud Lake WMA and Camas National Wildlife Refuge rely on streamflow from Beaver and Camas Creeks, natural ground-water inflow, and ground-water withdrawals to fill and maintain area lakes. Market Lake WMA is maintained solely by natural ground-water inflow.

Changes in water use have contributed to concern by many water users in the study area about an adequate future supply of surface and ground water. Many tracts of land were converted to agricultural use between the late 1970's and 1989. These tracts were developed with irrigation systems that relied on ground water for supply. Concurrently, decreased reliance on subirrigation and systematic conversion to sprinkler

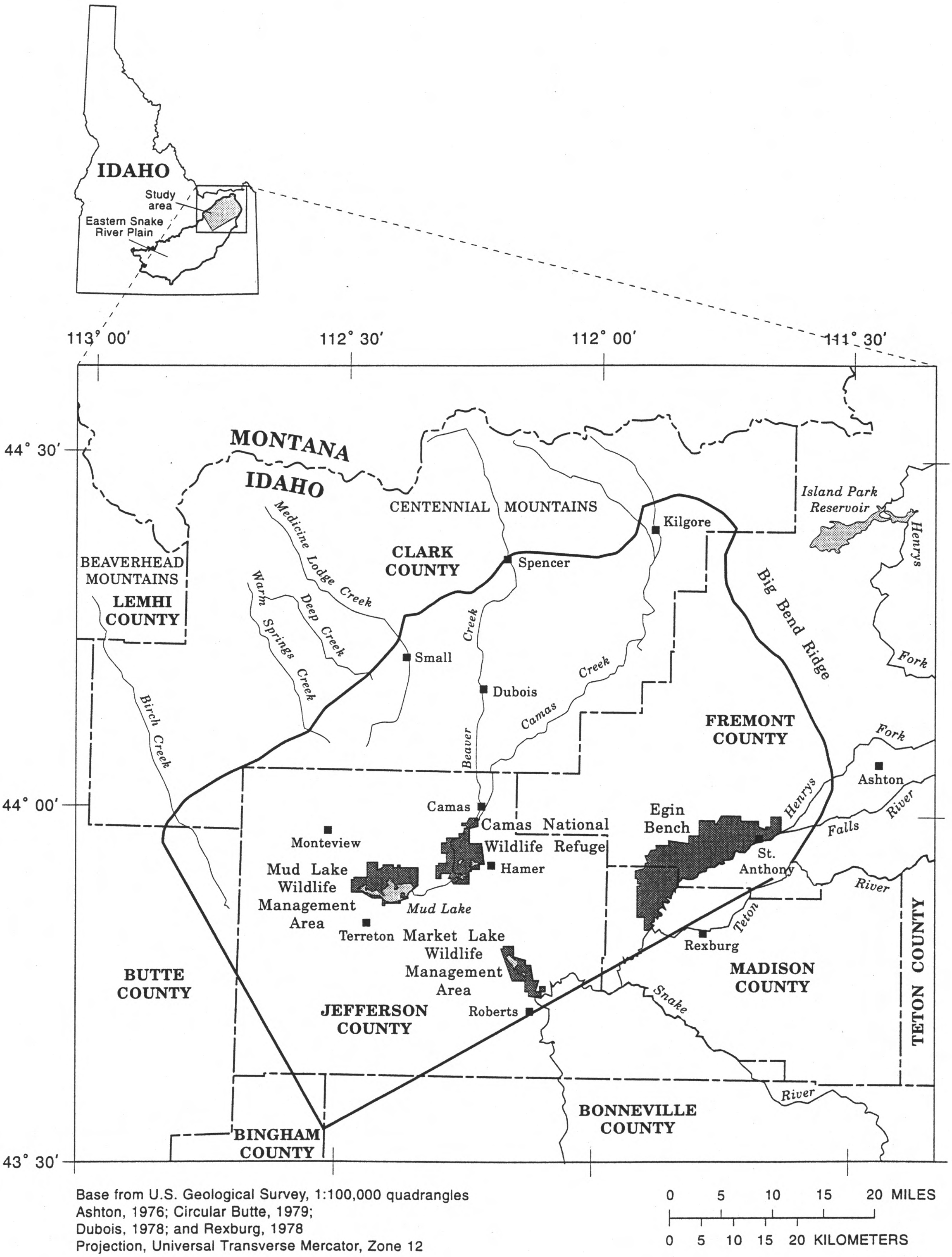


Figure 1. Location of study area.

irrigation on Egin Bench (fig. 1) were predicted to result in about 95,000 acre-ft less recharge to the Snake River Plain aquifer (King, 1987, p. 21). The need to evaluate the consequences of increased development and reduced recharge on future water levels and water supply resulted in a 3-year study that began in the spring of 1989. This study was made by the U.S. Geological Survey (USGS) in cooperation with the Idaho Department of Water Resources and the U.S. Department of Energy.

This report describes the use of a three-dimensional, finite-difference, numerical ground-water flow model to evaluate potential effects of water-use changes on ground-water levels and on losses from and gains to streams and lakes in the study area. A complete description of the geohydrology of the Mud Lake area and the numerical model that was calibrated to assumed steady-state conditions for 1980 is contained in a companion report (Spinazola, 1994).

GEOHYDROLOGIC SETTING

The surface of the eastern Snake River Plain consists of volcanic rocks and alluvial and windblown sediments (fig. 2). Basalt predominates on and under the plain and is less than 4,000 ft thick in the study area (Whitehead, 1986, sheet 2). Sediments that consist mainly of sand and gravel underlie the channels of the Henrys Fork and Snake River and are present in the alluvial fans that extend southward from the northwestern margin of the plain. Lakebeds that consist mainly of clay, silt, and sand predominate in the area around Mud Lake. Total thickness of sediments in the study area ranges from 0 to less than 1,000 ft (Whitehead, 1986, sheet 2). Basalt and sediment interbeds are present locally but are most prevalent around Mud Lake and progressively decrease from southwest to northeast (fig. 3).

The aquifer system in the eastern Snake River Plain is composed of saturated volcanic rocks and sediments. The top of the aquifer system is the water table. Several feet to several hundred feet of unsaturated volcanic rocks and sediments separate land surface from the water table. Minimum aquifer thickness is about 500 ft; maximum thickness is about 2,000 ft. The effective base of the aquifer system is dense, older basalt or rhyolite (Whitehead, 1986, sheet 2).

Precipitation on and adjacent to the study area determines the supply of surface and ground water in the study area. Medicine Lodge, Beaver, and Camas Creeks; Wood's diversion, Mud Lake, Henrys Fork, and the Snake River; and lakes on Camas National Wildlife Refuge and Market Lake WMA are hydraulically connected with and lose water to or gain water from the aquifer system (fig. 4).

Ground water generally moves from northeast to southwest, and water-table altitudes range from about 4,500 ft above sea level near the southwestern corner of the study area to about 6,200 ft in the northeastern part (fig. 5). Generally, ground water nearest land surface is unconfined, but confined conditions are associated with basalt and sediment interbeds in the area around Mud Lake.

Recharge to the aquifer system is from precipitation and irrigation, underflow from tributary drainage basins and from the eastern Snake River Plain aquifer system across part of the southeastern boundary of the study area, and losses from streams and lakes. Discharge from the aquifer system includes underflow across the southwestern and part of the southeastern boundaries of the study area to the eastern Snake River Plain aquifer system, gains to streams and lakes, withdrawals from wells, and flowing wells.

Table 1. Target and simulated losses from and gains to stream and lake segments for 1980, Mud Lake area of the eastern Snake River Plain

[Losses and gains are reported in acre-feet per year to two significant figures for calendar year 1980; segments are identified on figure 4; —, indicates no data available]

Segment	Target loss	Target gain	Simulated loss	Simulated gain
Medicine Lodge Creek	45,000	0	45,000	0
Beaver Creek	17,000	0	17,000	0
Camas Creek:				
Upper segment	9,300	0	9,300	0
Middle segment	1,500	0	1,400	0
Rays Lake segment	13,000	0	13,000	0
Mud Lake segment	20	0	17	2
Mud Lake	11,000	0	11,000	0
Wood's diversion	8,400	0	8,400	0
Henrys Fork	—	39,000	7,400	47,000
Snake River	—	68,000	1,400	69,000
Camas National Wildlife Refuge	8,400	—	8,400	160
Market Lake Wildlife Management Area	—	1,000	3	1,100
TOTAL	110,000	110,000	120,000	120,000

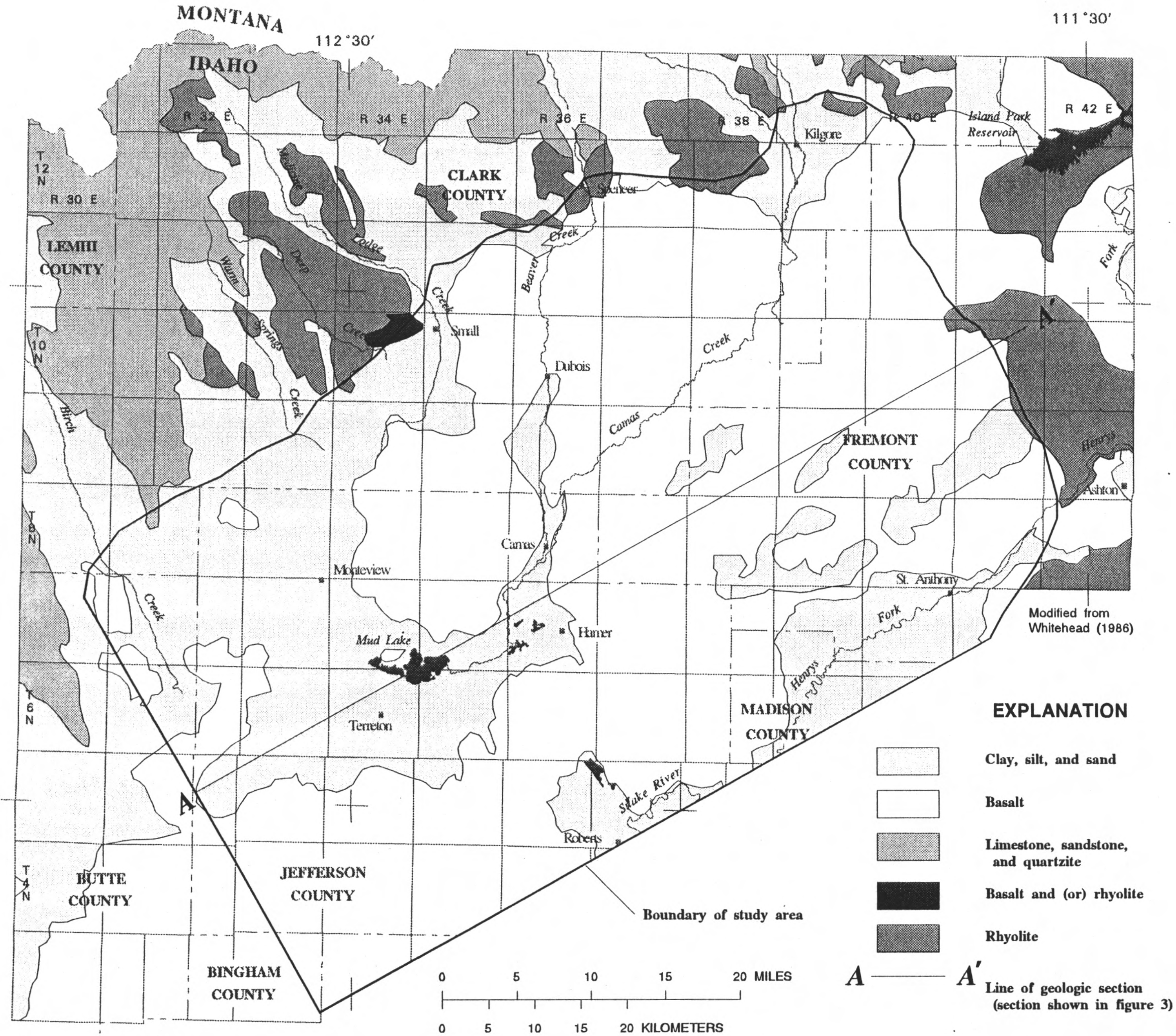


Figure 2. Surficial geology.

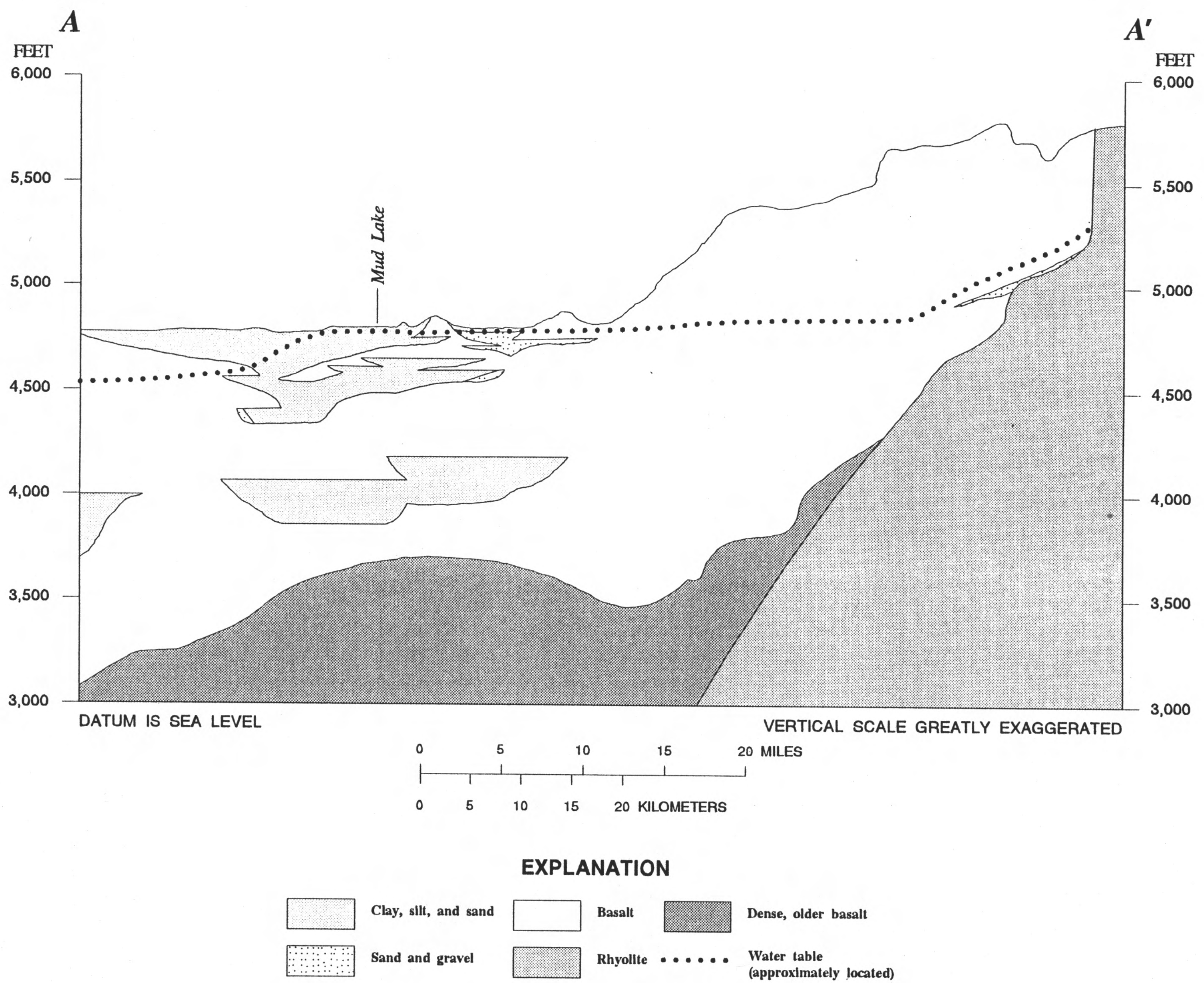


Figure 3. Generalized geologic section A–A'.

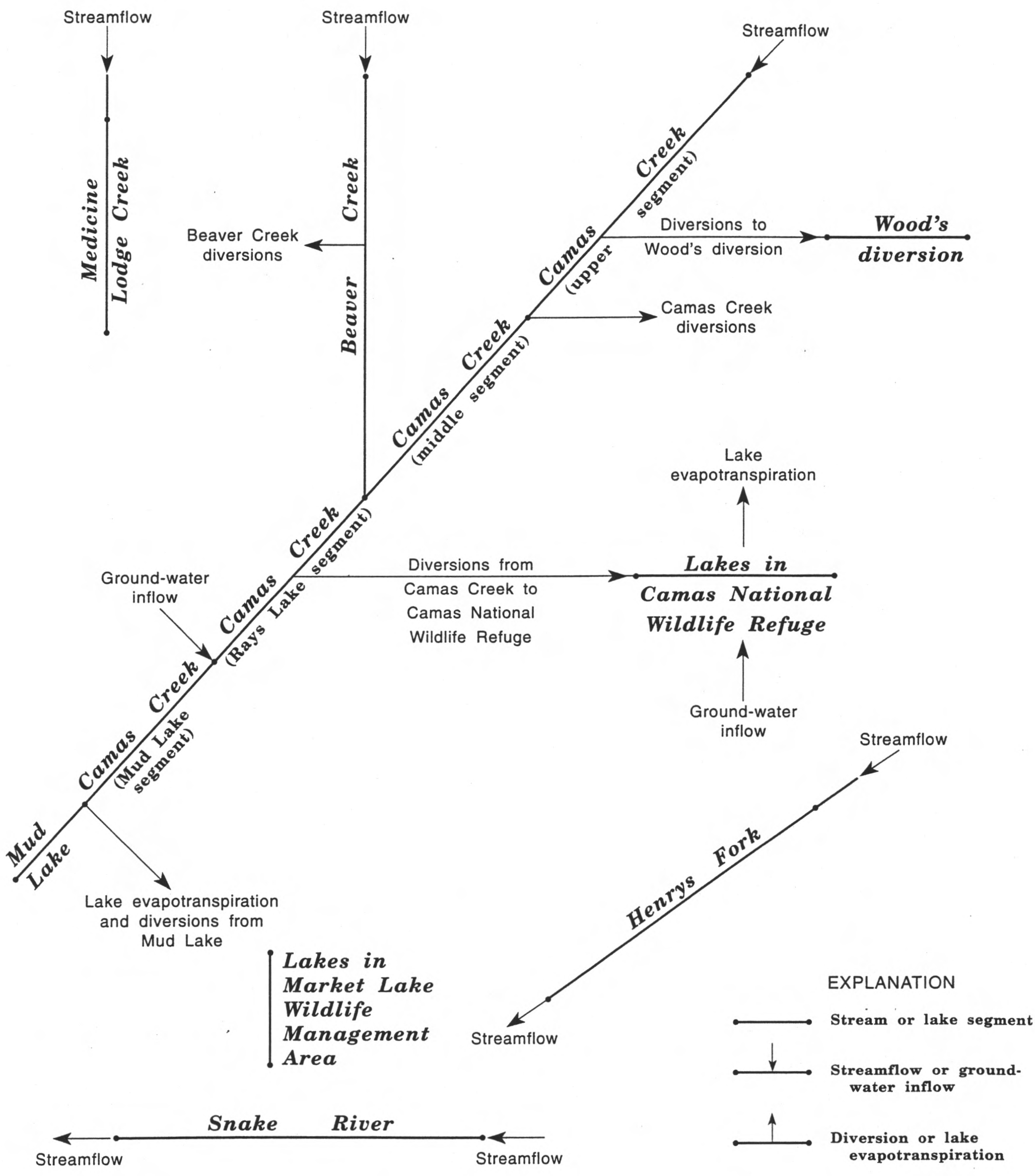


Figure 4. Stream and lake segments, streamflow, ground-water inflow, diversions, and lake evapotranspiration. (Locations of stream and lake segments shown on figure 6)

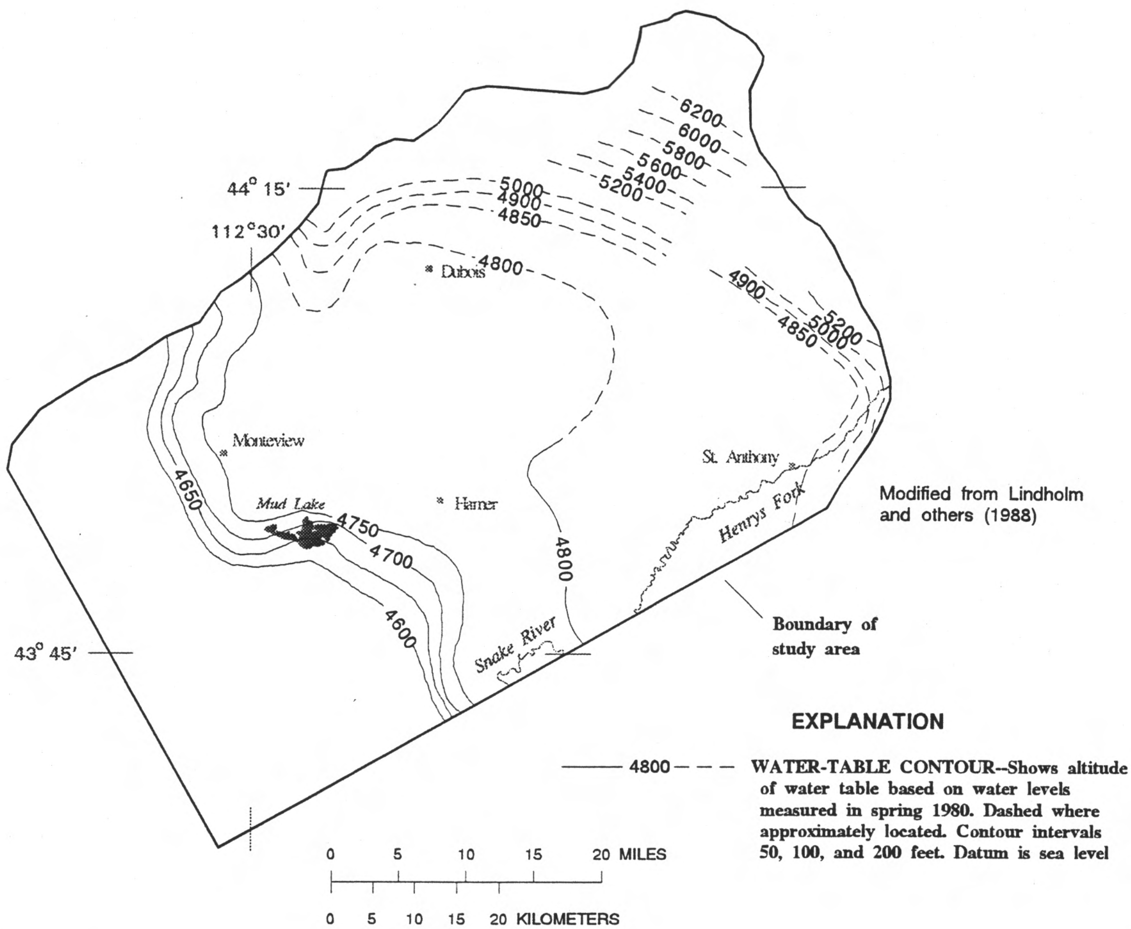


Figure 5. Water table, spring 1980.

NUMERICAL MODEL

The USGS modular, three-dimensional, finite-difference ground-water flow model (McDonald and Harbaugh, 1988) was used to simulate ground-water flow and water levels in the aquifer (Spinazola, 1994). The model grid contained 40 rows, 64 columns, and 5 layers. Cells along rows and columns were 1 mi on a side. Thickness of model layers 1, 2, and 3 represented constant-thickness intervals of volcanic rocks and sediments below the water table. Cells in layers 1 (fig. 6a) and 2 (fig. 6b) represented a thickness of 100 ft each; cells in layer 3 (fig. 6b) represented a thickness of 300 ft. The lateral extent of cells in model layers 4 and 5 was decreased successively to represent thinning of basalt and sediments toward the margin of the plain. Cells in layers 4 (fig. 6c) and 5 (fig. 6d) represented thicknesses of 500 ft or less and 1,000 ft or less, respectively. Active grid cells represented a three-dimensional volume of the aquifer system and were assigned representative values for aquifer properties, boundary conditions, recharge, and discharge.

No-flow boundaries (Franke and others, 1987, p. 3) were specified in all layers to represent the natural extent of the aquifer system along the northwestern and northeastern margins of the study area, a flowline along part of the southeastern boundary of the study area, and the bottom of the aquifer system. Head-dependent flux boundaries (Franke and others, 1987, p. 4) were used to simulate underflow between the modeled area and areas adjacent to the model along the southwestern boundary in layers 1–5 and along part of the southeastern boundary in layer 1, losses and gains for stream and lake segments, and discharge from flowing wells. Underflow between the study area and areas adjacent to the study area was simulated with the general-head boundary package (McDonald and Harbaugh, 1988, chap. 11). Losses from and gains to stream and lake segments were simulated with the streamflow-routing package (Prudic, 1989). Discharge from flowing wells was simulated with the drain package (McDonald and Harbaugh, 1988, chap. 9). A free-surface boundary (Franke and others, 1987, p. 5) simulated the position of the water table in model layer 1. Specified-flux boundaries (Franke and others, 1987, p. 4) were used to represent recharge from precipitation and irrigation, underflow from tributary basins along the margin of the plain, and withdrawals from pumping wells. Recharge to active cells in the model grid was assigned with the recharge package (McDonald and Harbaugh, 1988, chap. 7); underflow and withdrawals were assigned with the well package (McDonald and Harbaugh, 1988, chap. 8). The model was calibrated to assumed steady-state conditions for calendar year 1980.

The ability of the model to reproduce field conditions was evaluated by the correspondence between values for measured and simulated ground-water levels, target and simulated losses from and gains to stream and lake segments, and measured and simulated discharge from flowing wells. The water-table map based on 1980 measured water levels (Lindholm and others, 1988) was compared with a map based on simulated water levels for model layer 1 (fig. 7). Similarities between the two maps include the steep hydraulic gradient between the S-shaped bends in the 4,600- and 4,700-ft contours, the width and shape of the low-gradient area between the 4,700- and 4,900-ft contours, and the steep gradient where the water table exceeds 4,900 ft. Simulated losses from and gains to stream and lake segments closely approximated target values (table 1). Target values were obtained independently of the model from measurements and estimates (Spinazola, 1994). The 10,000-acre-ft difference between total target and simulated losses and gains is due largely to simulated losses to Henrys Fork and the Snake River. Target values include the sum of losses and gains in one net value. Net simulated losses and gains were within 2 percent of target values for stream or lake segments where differences between the two exceeded 100 acre-ft. Simulated discharge from flowing wells in 1980 equaled the measured value of 10,000 acre-ft (Spinazola, 1994, p. 61).

SIMULATION OF WATER LEVELS AND GROUND-WATER FLOW

The numerical model developed by Spinazola (1994) was used to simulate steady-state ground-water levels and ground-water flow in the Mud Lake area for average 1980–90 hydrologic conditions and for seven water-use alternatives. Each water-use alternative, identified by the letters A through G, represented a change from average 1980–90 conditions of withdraw-

Table 2. Streamflow, ground-water inflow, diversion, and lake evapotranspiration data for stream and lake segments for 1980 and average 1980–90 conditions, and for water-use alternatives A through G

[All values reported in acre-feet per year to two significant figures; stream and lake segments, streamflow, ground-water inflow, diversions, and lake evapotranspiration are identified on figure 4]

Name of stream or lake segment, ground-water inflow, diversion, or lake evapotranspiration	Streamflow, ground-water inflow, diversion, or lake evapotranspiration: 1980	Streamflow, ground-water inflow, diversion, or lake evapotranspiration: Average 1980–90 and water-use alternatives A through G
Medicine Lodge Creek	45,000	49,000
Beaver Creek	29,000	36,000
Beaver Creek diversion	3,500	5,800
Camas Creek	80,000	90,000
Wood's diversion	8,400	7,400
Camas Creek diversion	6,700	13,000
Camas Creek diversions from Rays Lake segment to lakes on Camas National Wildlife Refuge	11,000	9,600
Lake evapotranspiration minus ground-water inflow for lakes on Camas National Wildlife Refuge	2,600	[1]3,000
Ground-water inflow to Mud Lake segment of Camas Creek	73,000	[2]69,000
Lake evapotranspiration and diversions from Mud Lake	75,000	[3]94,000
Henrys Fork	1,200,000	1,300,000
Snake River	2,800,000	3,200,000
Lakes on Market Lake Wildlife Management Area	0	0

[1] 5,000 for water-use alternative C.
[2] 0 for water-use alternative D.
[3] 50,000 for water-use alternative D.

als from wells and (or) recharge from precipitation and irrigation in different parts of the study area. Hydrologic data used to construct model data sets for average 1980–90 conditions are documented in a companion report (Spinazola, 1994). Streamflow, ground-water inflow, diversion, and lake evapotranspiration data were applied to the streamflow-routing package to simulate losses from and gains to stream and lake segments with the numerical model (table 2). The economic and institutional feasibility of water-use alternatives and responses to simulated results are not accounted for in this model or considered in the analysis and following discussion.

Average 1980–90 Conditions

Average 1980–90 hydrologic conditions were simulated to obtain a steady-state response of the aquifer system to average recharge and discharge during that period. Differences among model inputs for average 1980–90 conditions in comparison with 1980 conditions for streamflow (table 2), recharge from precipitation and irrigation, tributary underflow, and withdrawals from wells (table 3) produced differences in model results. The shape and values of water-table contours produced from simulated water levels for average 1980–90 conditions (fig. 8) are similar to those produced from simulated water levels for 1980 (fig. 7). Differences between the maps indicate that simulated average 1980–90 water levels were slightly higher than simulated 1980 water levels. Water-budget differences between inflow and outflow for average 1980–90 conditions and for 1980 (table 3) are consistent with water-level differences observed on the maps.

Recharge from precipitation and irrigation was 110,000 acre-ft greater and underflow from tributary basins was 10,000 acre-ft greater for average 1980–90 conditions than for 1980. Greater inflow from these two sources produced higher simulated water levels plus 40,000 acre-ft greater simulated stream and lake gains and 10,000 acre-ft less simulated stream and lake losses for average 1980–90 conditions (tables 4 and 1). Total flows specified for Medicine Lodge, Beaver, and Camas Creeks, Henrys Fork, and the Snake River were about 500,000 acre-ft greater for average 1980–90 conditions than for 1980 (table 2) and indicated that average runoff during 1980–90 exceeded that during 1980.

Table 3. Water budgets for 1980 and average 1980–90 conditions

[All values reported in acre-feet to two significant figures; recharge from precipitation and irrigation, underflow from tributary basins, and withdrawals from wells were determined from interpretation of hydrologic data; all other budget items were simulated by the numerical model]

Budget item	1980	Average 1980–90
INFLOW		
Recharge from precipitation and irrigation	660,000	770,000
Stream and lake losses	120,000	110,000
Underflow from tributary basins	450,000	460,000
Underflow across southeastern model boundary	49,000	43,000
TOTAL	1,300,000	1,400,000
OUTFLOW		
Withdrawals from wells	240,000	280,000
Stream and lake gains	120,000	160,000
Flowing wells	10,000	12,000
Underflow across southeastern model boundary	14,000	19,000
Underflow across southwestern model boundary	920,000	920,000
TOTAL	1,300,000	1,400,000

Table 4. Simulated losses from and gains to stream and lake segments for average 1980–90 conditions

[All values reported in acre-feet to two significant figures]

Segment	Loss	Gain
Medicine Lodge Creek	49,000	0
Beaver Creek	16,000	0
Camas Creek:		
Upper segment	9,100	0
Middle segment	1,400	0
Rays Lake segment	12,000	0
Mud Lake segment	15	2
Mud Lake	6,400	25
Wood's diversion	7,400	0
Henrys Fork	3,700	80,000
Snake River	920	76,000
Camas National Wildlife Refuge	6,500	320
Market Lake Wildlife Management Area	3	1,500
TOTAL	110,000	160,000

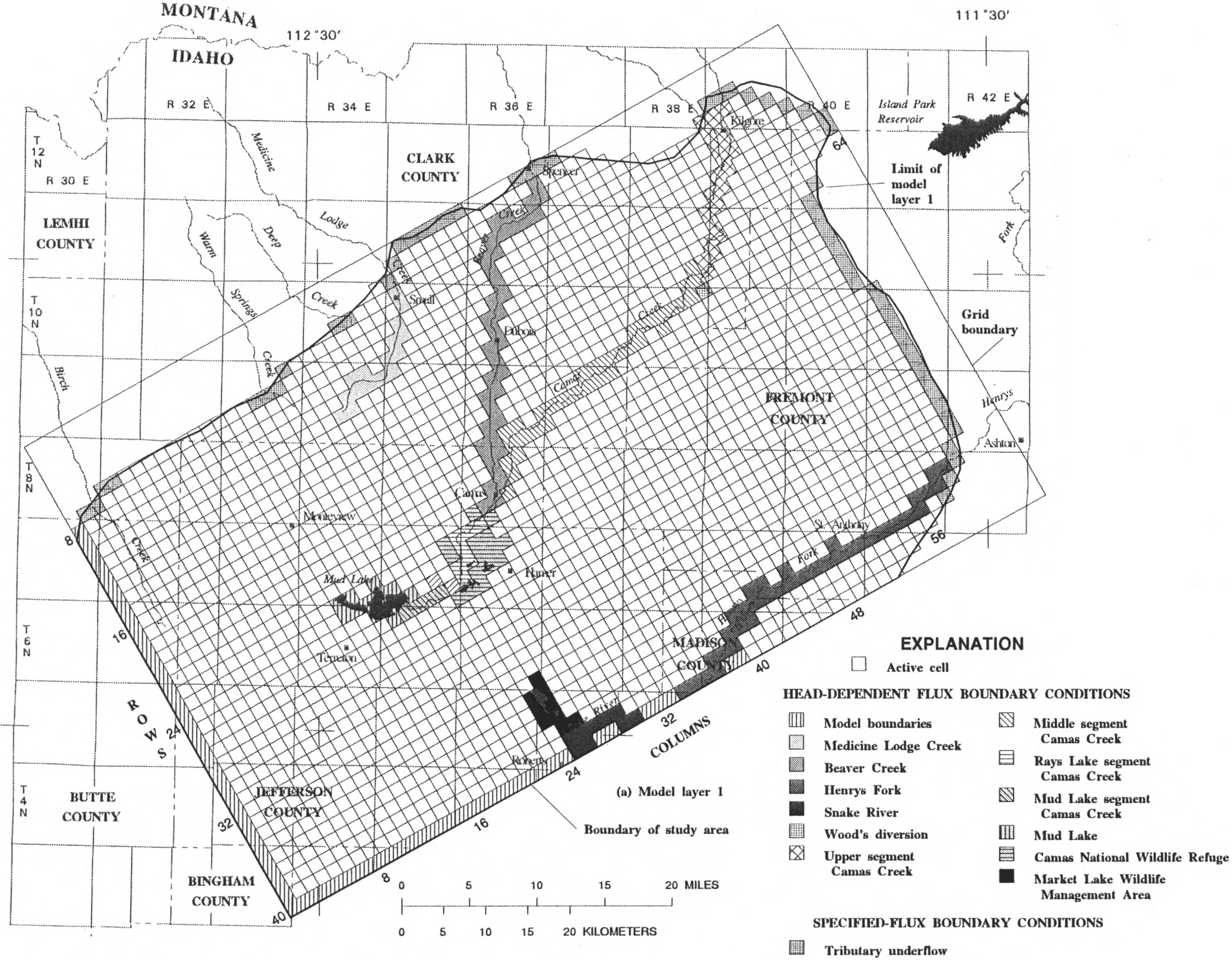
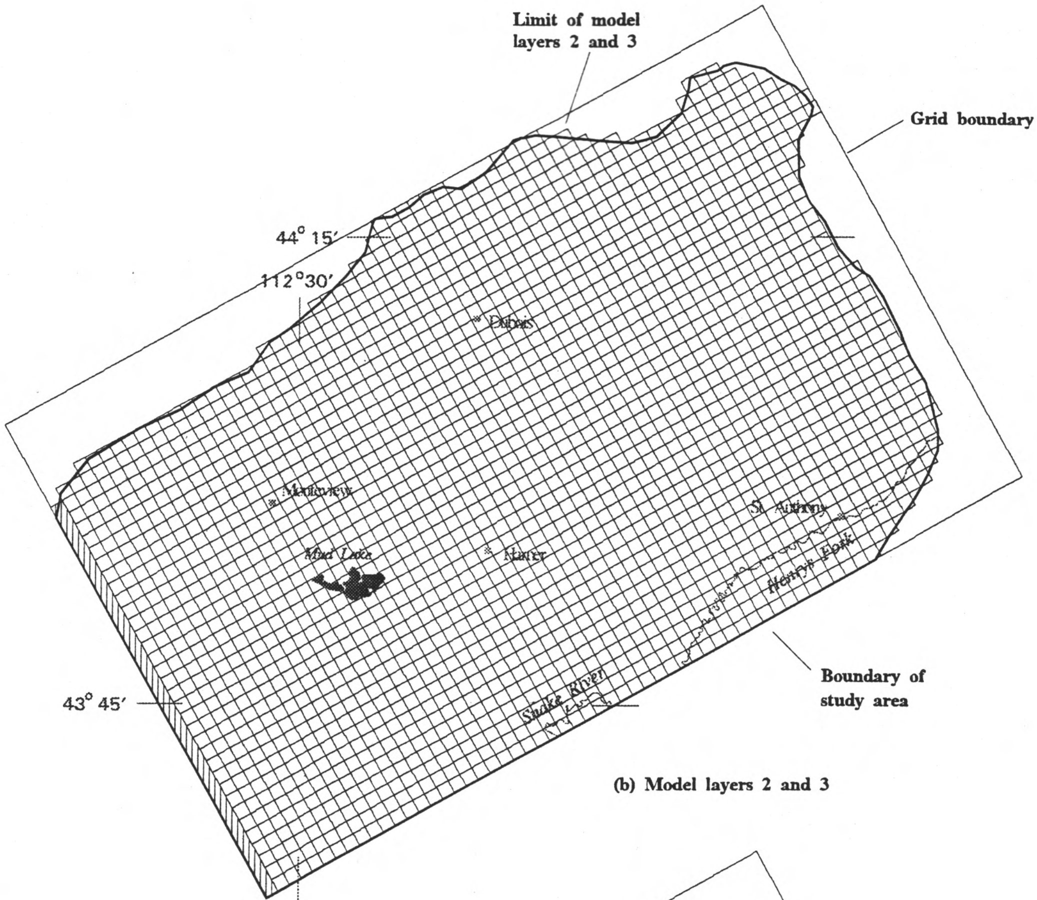
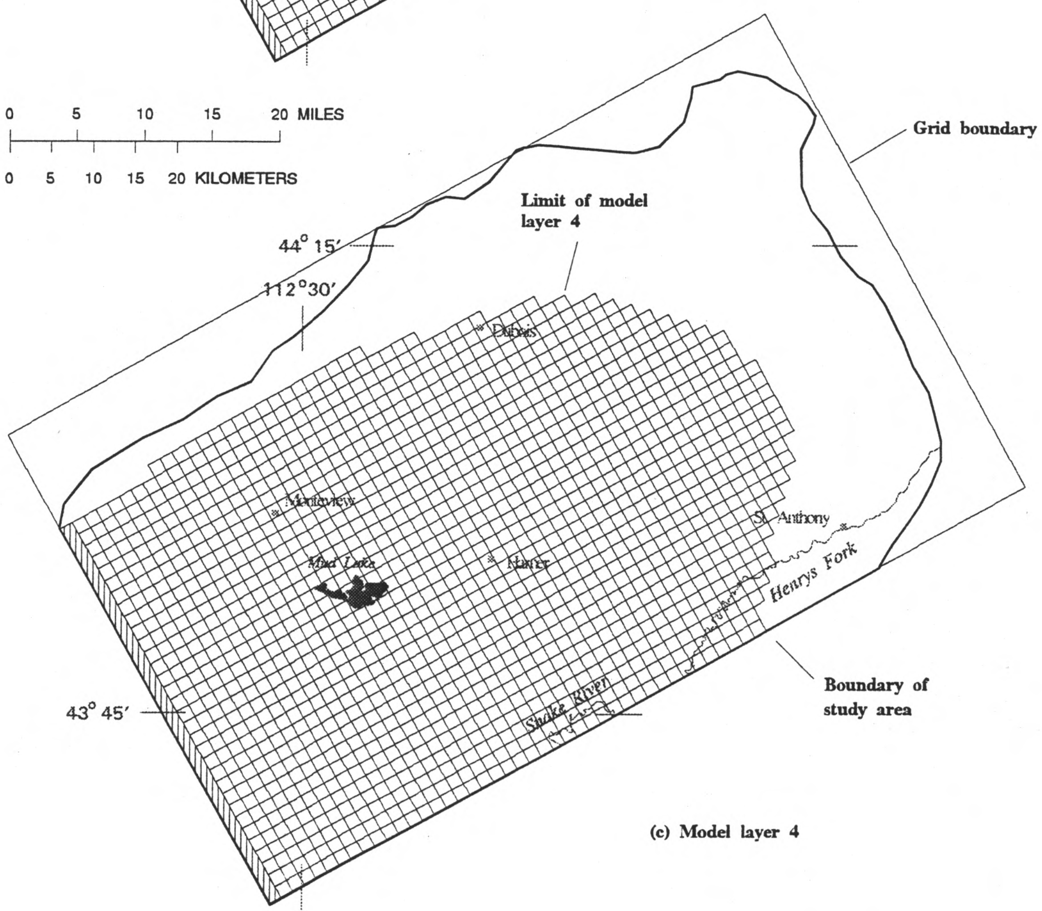


Figure 6. Grid and boundary conditions for model layers 1–5.



(b) Model layers 2 and 3



(c) Model layer 4

Figure 6. Grid and boundary conditions for model layers 1–5—Continued.

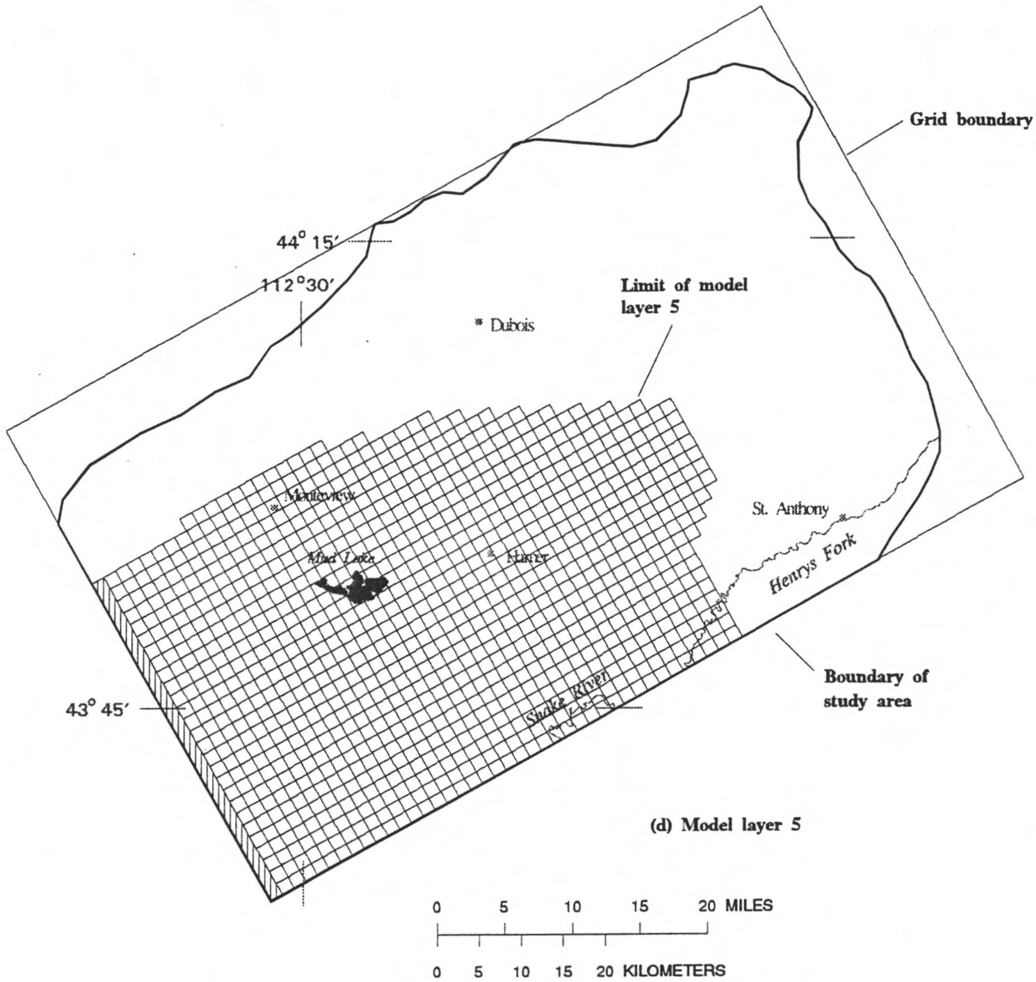


Figure 6. Grid and boundary conditions for model layers 1–5—Continued.

Water-Use Alternatives

Seven water-use alternatives were simulated to obtain steady-state response of the aquifer system to reduced withdrawals from wells (alternatives A through E), increased withdrawals in areas that could potentially support additional irrigation development (alternative F), and reduced recharge from precipitation and irrigation on Egin Bench (alternative G). Steady-state response then was compared with results from the simulation of average 1980–90 conditions. Differences from average 1980–90 conditions in withdrawals from wells and in recharge from precipitation and irrigation for each water-use alternative are listed in table 5. Wells associated with reduced withdrawals are identified on figures 9 through 13 (back of report) for individual alternatives A through E. Withdrawals associated with each set of wells were removed from the data set, and recharge from precipitation and irrigation was recalculated in affected areas to reflect changes due to each water-use alternative. Wells associated with alternative A were installed progressively between 1985 and 1990. Therefore, withdrawals from wells and recharge from precipitation and irrigation associated with alternative A were normalized to average 1980–90 conditions to obtain a meaningful comparison among simulation results from the seven alternatives. Additional withdrawals associated with alternative F were assigned by application of the average rate of withdrawal from nearby wells to model grid cells that corresponded to areas that could potentially support additional irrigation development (fig. 14, back of report). Recharge from precipitation and irrigation associated with alternative F was assigned by application of the recharge rate for nearby irrigated areas to areas where increased withdrawals were assigned. Withdrawals from wells associated with water-use alternative G were the same as for average 1980–90 conditions, but recharge from precipitation and irrigation was reduced by 96,000 acre-ft. The reduction represented the change in recharge predicted as a result of the conversion from subirrigation to sprinkler irrigation (King, 1987, p. 21) on Egin Bench (fig. 15, back of report).

Streamflow, ground-water inflow, diversion, and lake evapotranspiration data specified for stream and lake segments were the same for average 1980–90 conditions and all water-use alternatives, with three exceptions (table 2). Diversions from Camas Creek and ground-water inflow provide water to lakes on Camas National Wildlife Refuge (fig. 4). The wells removed from the simulation for alternative C were those that provided ground-water inflow to lakes on the refuge. Reduced withdrawals from wells (equal to reduced ground-water inflow) of 2,000 acre-ft (table 5) increased the value of the item "Lake evapotranspiration minus ground-water inflow for lakes on Camas National Wildlife Refuge" to 5,000 acre-ft for alternative C compared with 3,000 acre-ft for the other alternatives (table 2).

Some of the wells removed from the simulation for alternative D provided ground-water inflow to the Mud Lake segment of Camas Creek. With these wells removed, ground-water inflow to the Mud Lake segment of Camas Creek was set to zero for alternative D (table 2). Diversions from Mud Lake for all simulations except alternative D were the sum of diversions from surface- and ground-water sources. Average 1980–90 diversions from Mud Lake were about 41,000 acre-ft from surface-water sources and about 44,000 acre-ft from ground-water sources (Spinazola, 1994, p. 23, fig. 15). Diversions from Mud Lake were limited to surface-water sources for alternative D and were reduced by 44,000 acre-ft (table 2) compared to all other simulations. An algorithm was developed to calculate the reduction in irrigated area needed to maintain the same application rate for Mud Lake diversions from surface-water sources alone as for diversions from both surface- and ground-water sources. The algorithm was incorporated in a computer program that was used to produce the recharge data set for alternative D.

Table 5. Differences between water budgets for average 1980–90 conditions and water-use alternatives A through G

[All values reported in acre-feet to two significant figures; values for recharge from precipitation and irrigation, underflow from tributary basins, and withdrawals from wells indicate changes in model input values and were determined from interpretation of hydrologic data; all other budget items listed were output by the numerical model; negative (-) differences identify input or output values less than average 1980–90 budget values]

Budget item	Water-use alternative A	B	C	D	E	F	G
Inflow							
Recharge from precipitation and irrigation	-2,000	-10,000	0	-18,000	-27,000	4,000	-96,000
Stream and lake losses	-1,200	-7,100	-1,700	-5,300	-16,000	3,800	13,000
Underflow from tributary basins	0	0	0	0	0	0	0
Underflow across southeastern model boundary	-400	-2,200	0	-1,100	-8,200	1,300	7,200
Outflow							
Withdrawals from wells	-7,000	-43,000	-2,000	-34,000	-190,000	22,000	0
Stream and lake gains	1,600	10,000	490	6,200	43,000	-5,000	-47,000
Flowing wells	500	2,700	100	3,900	10,000	-1,600	-4,900
Underflow across southeastern model boundary	0	2,000	0	1,000	11,000	-1,000	-6,000
Underflow across southwestern model boundary	2,000	10,000	1,000	-1,000	80,000	-5,000	-17,000

DISCUSSION OF SIMULATION RESULTS

Simulated responses of water levels and flow in the aquifer system to changes in recharge and discharge from water-use alternatives A through G were compared with average 1980–90 hydrologic conditions in terms of water-level difference maps (figs. 9 through 15), differences between water budgets (table 5), and differences between losses from and gains to stream and lake segments (table 6). A few details need to be considered before conclusions are drawn from the simulation results presented in this report. Simulations were made to represent average 1980–90 conditions, and these conditions were hypothetical. Difference maps and values of water-budget differences and differences between losses and gains need to be viewed in general terms of one alternative relative to another and not as a precise prediction of the response of the ground-water flow system to conditions represented by any individual alternative. In many cases, reported difference values for an individual alternative were quite small. Although the significance of small differences in relation to the magnitude of the overall water budget is arguable, small differences were reported to provide a basis to compare the results of any one alternative with all others. Finally, results from individual alternatives are not additive. The combined effects of two or more individual alternatives may be different from the sum of the individual effects. The effects of imposing two or more simulation alternatives on the system can be accurately evaluated only by making an independent simulation that includes the cumulative changes in withdrawals from wells and (or) recharge from precipitation and irrigation.

Simulated water-level rises resulted from water-use alternatives A, B, C, D, and E that corresponded to reductions in withdrawals from wells from average 1980–90 conditions (table 5). Simulated rises were greatest where wells were removed during a simulation and were as much as 2 ft for alternative A (fig. 9), 6 ft for alternative B (fig. 10), 0.1 ft for alternative C (fig. 11), 15 ft for alternative D (fig. 12), and 40 ft for alternative E (fig. 13). Declines of as much as 25 ft were simulated for alternative D in an area south and west of Mud Lake (fig. 12) where recharge from precipitation and irrigation was reduced by as much as 18,000 acre-ft (table 5). Losses from individual stream and lake segments were reduced as much as 4,700 acre-ft and gains were increased as much as 19,000 acre-ft among alternatives A, B, C, D, and E compared with average 1980–90 conditions (table 6) due to the simulated water-level rises. Simulated losses from Camas Creek were less than average 1980–90 conditions by about 210 acre-ft for alternative A; 1,500 acre-ft for alternative B; 0 acre-ft for alternative C; 1,100 acre-ft for alternative D; and 4,900 acre-ft for alternative E. No differences in gains to Camas Creek were simulated between average 1980–90 conditions and alternatives A, B, C, D, and E. Simulated underflow into the study area was as much as 8,200 acre-ft less and simulated

Table 6. Differences between simulated losses from and gains to stream and lake segments for average 1980–90 conditions and water-use alternatives A through G

[All values reported in acre-feet to two significant figures; negative (-) differences identify less than average 1980–90 values]

	Water-use alternative													
	A		B		C		D		E		F		G	
Segment	Loss	Gain	Loss	Gain	Loss	Gain	Loss	Gain	Loss	Gain	Loss	Gain	Loss	Gain
Medicine Lodge Creek....	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Beaver Creek..................	0	0	-300	0	0	0	-100	0	-900	0	200	0	500	0
Camas Creek segments:														
Upper	0	0	-20	0	0	0	-20	0	-60	0	10	0	40	0
Middle	-10	0	-40	0	0	0	-20	0	-100	0	20	0	40	0
Rays Lake	-200	0	-1,400	0	0	0	-1,100	0	-4,700	0	800	0	2,300	0
Mud Lake	0	0	-1	0	0	0	-1	0	-4	0	0	0	1	0
Mud Lake.......................	-600	9	-2,700	740	-100	0	-2,200	1,200	-3,600	8,900	2,200	-25	5,700	-25
Wood's diversion	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Henrys Fork	-110	900	-650	5,500	-10	0	-340	2,900	-1,600	19,000	310	-2,700	4,200	-37,000
Snake River....................	-34	600	-210	3,200	0	0	-110	1,700	-840	11,000	110	-1,600	600	-9,400
Camas National Wildlife Refuge...........	-280	71	-1,800	420	-1,600	490	-1,400	260	-4,600	3,000	170	-73	50	-220
Market Lake Wildlife Management Area........	0	30	0	190	0	0	0	100	0	740	0	-100	0	-560

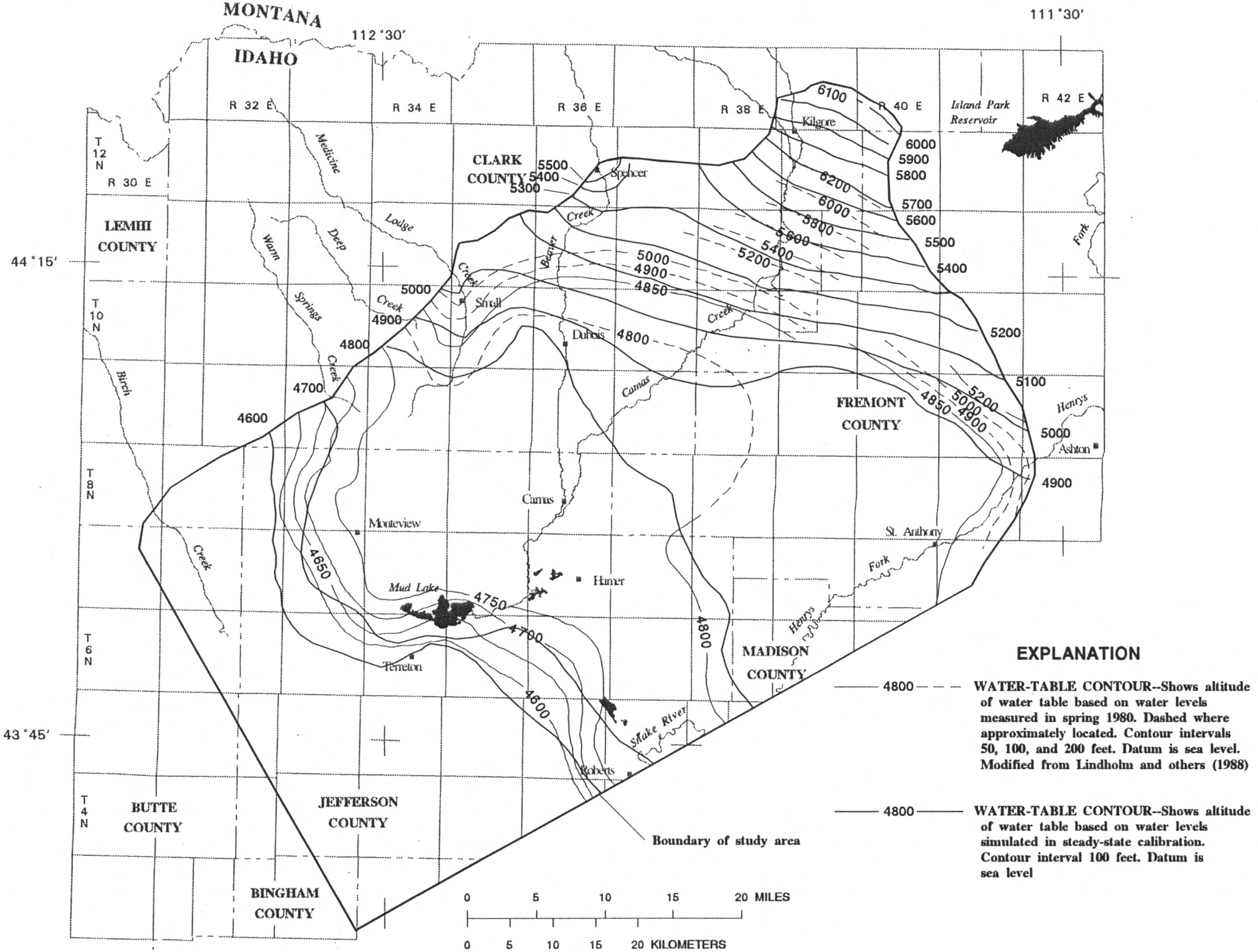


Figure 7. Measured and simulated water tables, 1980

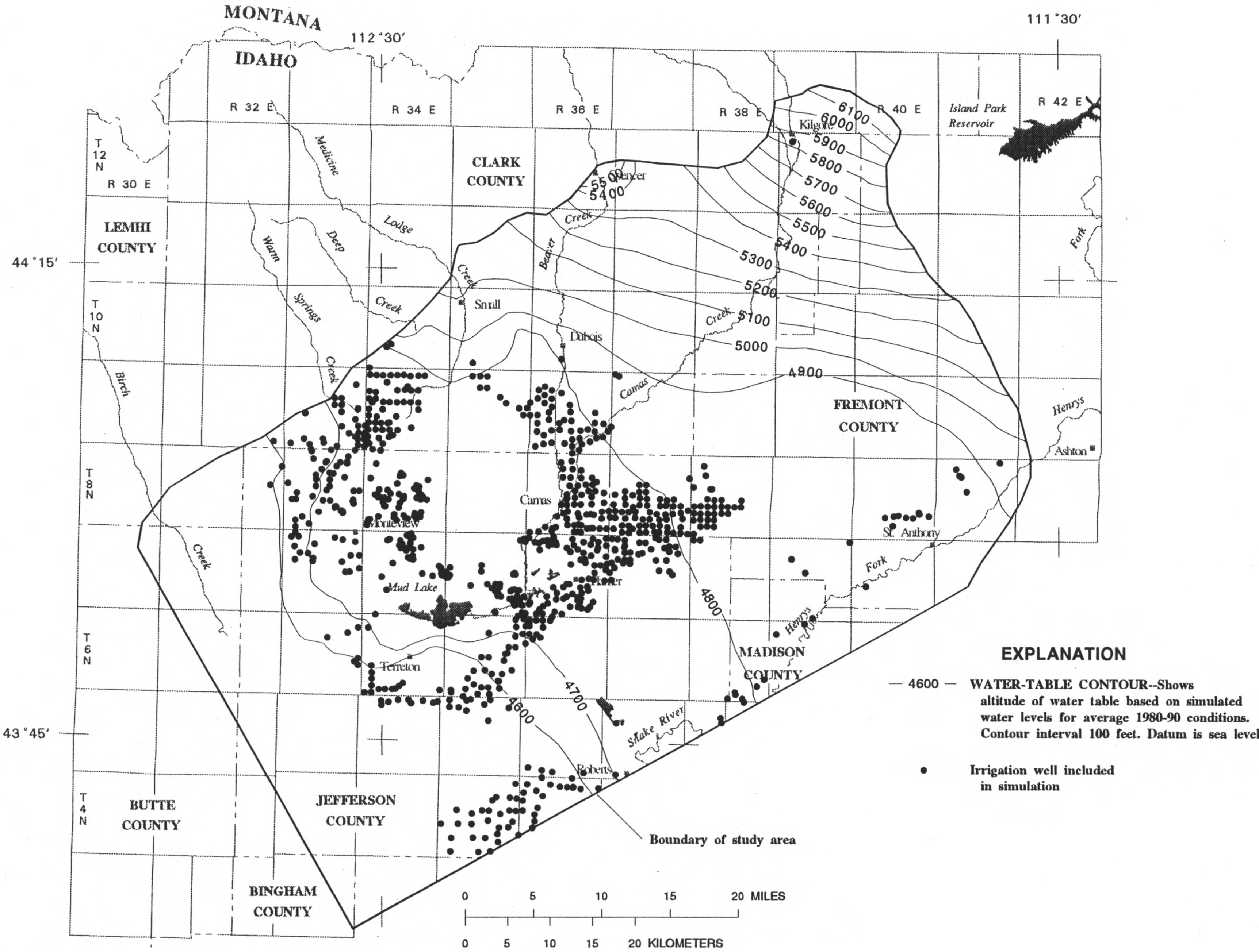


Figure 8. Simulated water table, average 1980–90 conditions.

underflow out of the study area was as much as 91,000 acre-ft greater among alternatives A, B, C, D, and E compared to average 1980–90 conditions (table 5).

Simulated water-level declines between average 1980–90 conditions and alternatives F and G corresponded to increased ground-water withdrawals for alternative F and decreased recharge from precipitation and irrigation for alternative G compared with average 1980–90 conditions. Simulated declines were as great as 15 ft for alternative F (fig. 14) and 10 ft for alternative G (fig. 15). Stream and lake losses from individual segments were as much as 5,700 acre-ft greater and gains were as much as 37,000 acre-ft less for alternatives F and G compared with average 1980–90 conditions due to simulated water-level declines (table 6). Simulated losses from Camas Creek were greater than average 1980–90 conditions by about 830 acre-ft for alternative F and 2,400 acre-ft for alternative G. No differences in gains to Camas Creek were simulated between average 1980–90 conditions and alternatives F and G. Simulated underflow into the study area was as much as 7,200 acre-ft greater and simulated underflow out of the study area was as much as 23,000 acre-ft less for alternatives F and G compared with average 1980–90 conditions (table 5).

SUMMARY

Water users in the Mud Lake study area in the northernmost part of the eastern Snake River Plain depend on an adequate supply of ground water for agriculture, wildlife, and other uses. Changes in water use have raised concerns about an adequate future supply of surface and ground water. Water users needed the ability to evaluate the consequences of increased ground-water development throughout the study area and 95,000 acre-ft less recharge from Egin Bench. A three-dimensional, finite-difference, numerical ground-water flow model of the aquifer system was used to evaluate potential effects of water-use changes on ground-water levels and on losses from and gains to streams and lakes in the study area.

The aquifer system that underlies the eastern Snake River Plain is composed predominantly of basalt. Total basalt thickness is less than 4,000 ft. Sediments that consist mainly of sand and gravel underlie the channels of the Henrys Fork and Snake River and are present in alluvial fans that extend southward from the northwestern margin of the plain. Lakebeds that consist mainly of clay, silt, and sand predominate around Mud Lake. Total sediment thickness is less than 1,000 ft. The top of the aquifer system is the water table. Several feet to several hundred feet of unsaturated volcanic rocks and sediments separate land surface from the water table. Minimum aquifer thickness is about 500 ft; maximum thickness is about 2,000 ft. The effective base of the aquifer system is dense, older basalt or rhyolite.

Medicine Lodge, Beaver, and Camas Creeks, Wood's diversion, Mud Lake, Henrys Fork, Snake River, and lakes on the Camas National Wildlife Refuge and Market Lake WMA are hydraulically connected with and lose water to or gain water from the aquifer system. Ground water generally moves from northeast to southwest, and water-table altitudes range from more than 4,500 ft near the southwestern corner of the study area to less than 6,200 ft in the northeastern part. Generally, ground water nearest land surface is unconfined, but confined conditions are associated with basalt and sediment interbeds in the area around Mud Lake. Recharge to the aquifer system is from precipitation and irrigation, underflow from tributary drainage basins and from the eastern Snake River Plain aquifer system across part of the southeastern boundary of the study area, and losses from streams and lakes. Discharge from the aquifer system includes underflow across the southwestern and part of the southeastern boundaries of the study area to the eastern Snake River Plain aquifer system, gains to streams and lakes, withdrawals from wells, and flowing wells.

The grid used in the numerical model contained 40 rows, 64 columns, and 5 layers. Cells represented a volume of the aquifer system and were assigned representative values for aquifer properties, boundary conditions, recharge, and discharge.

No-flow boundaries were specified to represent the natural extent of the aquifer system, a flowline along part of the southeastern boundary of the study area, and the bottom of the aquifer system. Head-dependent flux boundaries were specified along the southwestern boundary of the model grid in layers 1–5 and along the southeastern boundary for some cells in layer 1 to simulate underflow between the modeled area and the eastern Snake River Plain aquifer system adjacent to the study area. Head-dependent boundaries were used to simulate stream and lake losses and gains and discharge from flowing wells. A free-surface boundary simulated the position of the water table. Recharge from precipitation and irrigation, tributary underflow, and withdrawals from wells were assigned with specified-flux boundaries.

The numerical model was calibrated to assumed steady-state conditions for calendar year 1980. The ability of the model to reproduce field conditions was evaluated by the correspondence between values for measured and simulated water levels, losses from and gains to streams and lakes, and discharge from flowing wells. A water-table map based on 1980 water-level measurements was compared with a map based on steady-state simulated water levels for model layer 1. Measured and simulated water-table maps show a flat hydraulic gradient for much of the area between the 4,700- and 4,900-ft contours, a steeper gradient between the 4,600- and 4,700-ft contours, and the steepest gradient where the water table exceeds 4,900 ft. Simulated losses and gains closely approximated target values obtained independently of the model. Net simulated losses or gains were within 2 percent of target values where differences between the two exceeded 100 acre-ft. Simulated discharge from flowing wells matched the measured discharge of 10,000 acre-ft in 1980.

The numerical model was used to simulate steady-state ground-water levels and flow for average 1980–90 hydrologic conditions and seven water-use alternatives. The shape and values of water-table contours produced from simulated water levels for average 1980–90 conditions were similar to those produced from simulated water levels for 1980. Recharge from precipitation and irrigation and underflow from tributary basins were 120,000 acre-ft greater for average 1980–90 conditions than for 1980. The consequent rise in simulated water levels resulted in 40,000 acre-ft greater simulated stream and lake gains and 10,000 acre-ft less simulated losses.

Of the seven water-use alternatives, five represented reduced withdrawals from five different sets of wells, the sixth represented increased withdrawals in areas that could potentially support additional irrigation development, and the seventh represented reduced recharge from precipitation and irrigation on Egin Bench. One of the first five alternatives involved reduced ground-water inflow to lakes on Camas National Wildlife Refuge equal to reduced withdrawals from wells. Another of the five included a decrease in ground-water inflow to Mud Lake, a reduction in diversions from Mud Lake, and recalculation of recharge in the area irrigated by diversions from Mud Lake. Simulated results from each alternative were compared with results for average 1980–90 conditions.

Simulated water-level rises of 0.1 to 40 ft from average 1980–90 conditions resulted among the first five alternatives. Simulated declines of as much as 25 ft resulted from the alternative in which ground-water inflow to Mud Lake, diversions from Mud Lake, and irrigated area were reduced. Individual stream and lake losses were as much as 4,700 acre-ft less and gains were as much as 19,000 acre-ft greater due to simulated water-level rises. Simulated losses from Camas Creek were less than average 1980–90 conditions by about 210 to 4,900 acre-ft; no differences in gains to Camas Creek were simulated. Simulated underflow into the study area was as much as 8,200 acre-ft less and simulated underflow out of the study area was as much as 91,000 acre-ft greater.

Water-level declines of as much as 15 and 10 ft were simulated for the sixth and seventh alternatives, respectively. Stream and lake losses were as much as 5,700 acre-ft greater and gains were as much as 37,000 acre-ft less due to simulated water-level declines. Simulated losses from Camas Creek were greater than average 1980–90 conditions by about 830 acre-ft for the sixth alternative and 2,400 acre-ft for the seventh. No differences in gains to Camas Creek were simulated between average 1980–90 conditions and either alternative. Simulated underflow into the study area was as much as 7,200 acre-ft greater and simulated underflow out of the study area was as much as 23,000 acre-ft less for the last two alternatives compared with average 1980–90 conditions.

REFERENCES CITED

Franke, O.L., Reilly, T.E., and Bennett, G.D., 1987, Definition of boundary and initial conditions in the analysis of saturated ground-water flow systems—an introduction: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. B5, 15 p.

King, Verl, 1987, Egin Bench sprinkler irrigation impact study report: Boise, Idaho Department of Water Resources, 23 p.

Lindholm, G.F., Garabedian, S.P., Newton, G.D., and Whitehead, R.L., 1988 [1987], Configuration of the water table and depth to water, spring 1980, water-level fluctuations, and water movement in the Snake River Plain regional aquifer system, Idaho and eastern Oregon: U.S. Geological Survey Hydrologic Investigations Atlas HA–703, 1 sheet, scale 1:500,000.

McDonald, M.G., and Harbaugh, A.W., 1988, A modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations, book 6, chap. A1 [variously paged].

Prudic, D.E., 1989, Documentation of a computer program to simulate stream-aquifer relations using a modular, finite-difference, ground-water flow model: U.S. Geological Survey Open-File Report 88–729, 113 p.

Spinazola, J.M., 1994, Geohydrology and simulation of flow and water levels in the aquifer system in the Mud Lake area of the eastern Snake River Plain, eastern Idaho: U.S. Geological Survey Water-Resources Investigations Report 93–4227, 78 p.

Whitehead, R.L., 1986, Geohydrologic framework of the Snake River Plain, Idaho and eastern Oregon: U.S. Geological Survey Hydrologic Investigations Atlas HA–681, 3 sheets, scale 1:1,000,000.

FIGURES 9 – 15

page 23 follows

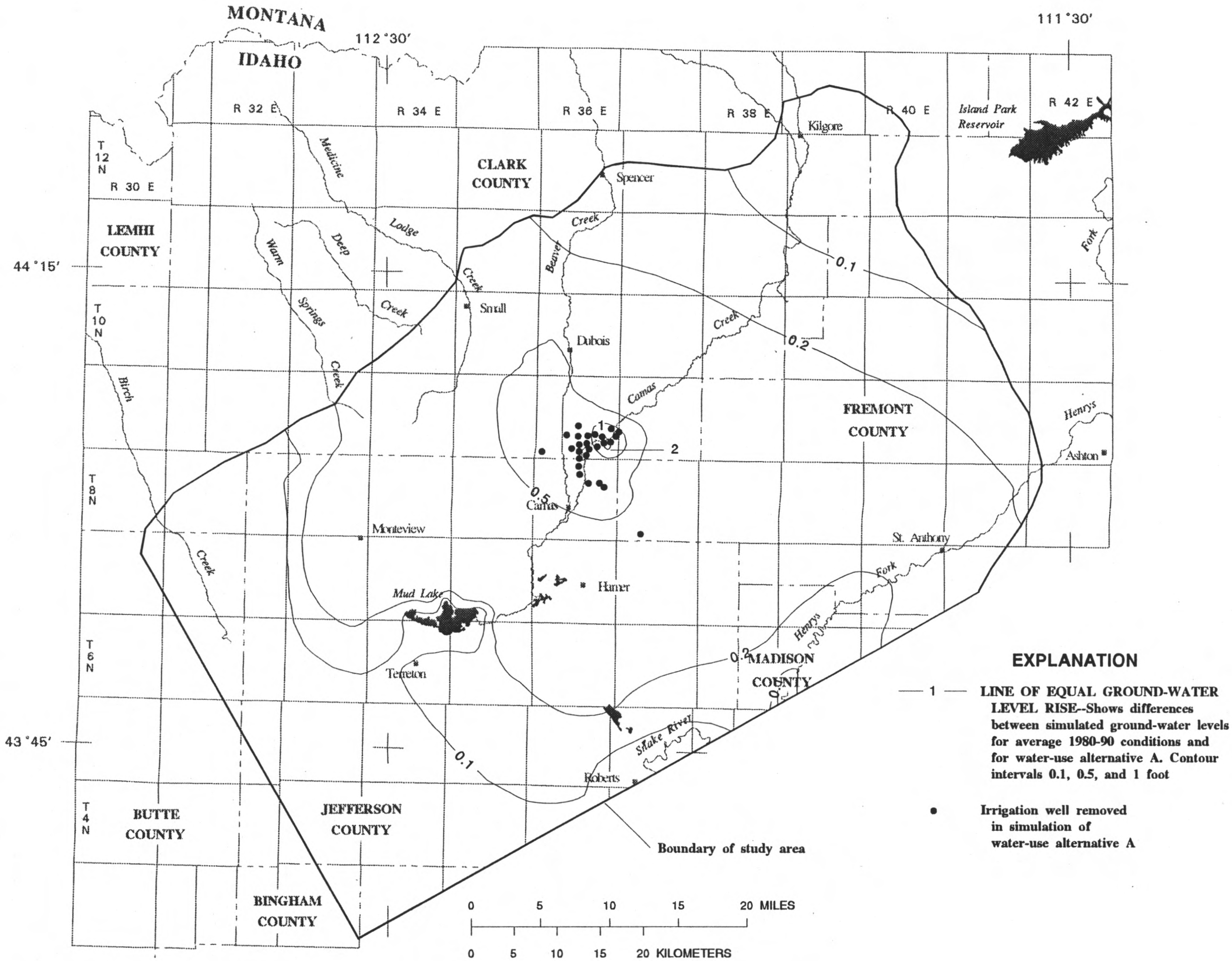


Figure 9. Differences between simulated ground-water levels for average 1980–90 conditions and for water-use alternative A.

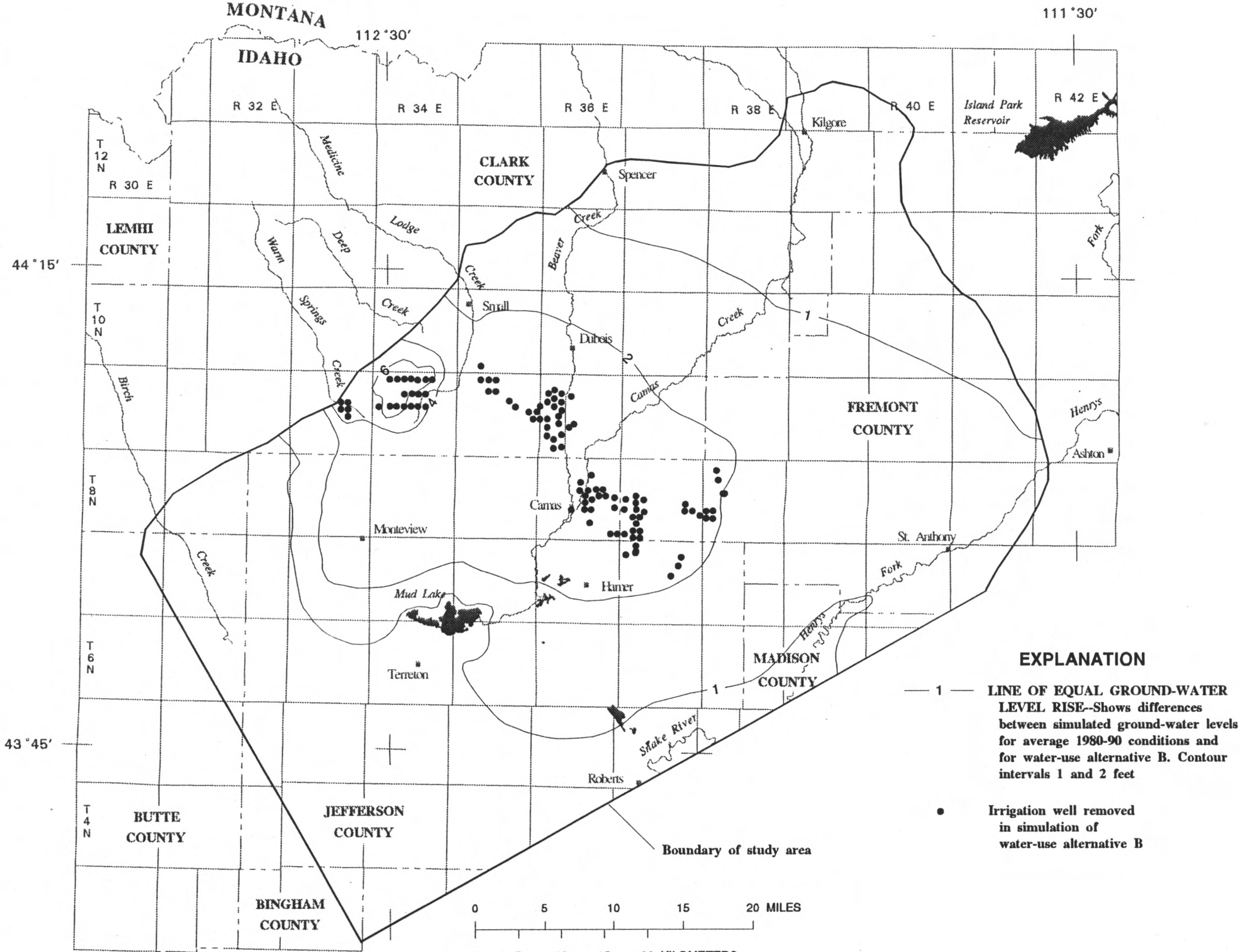


Figure 10. Differences between simulated ground-water levels for average 1980–90 conditions and for water-use alternative B.

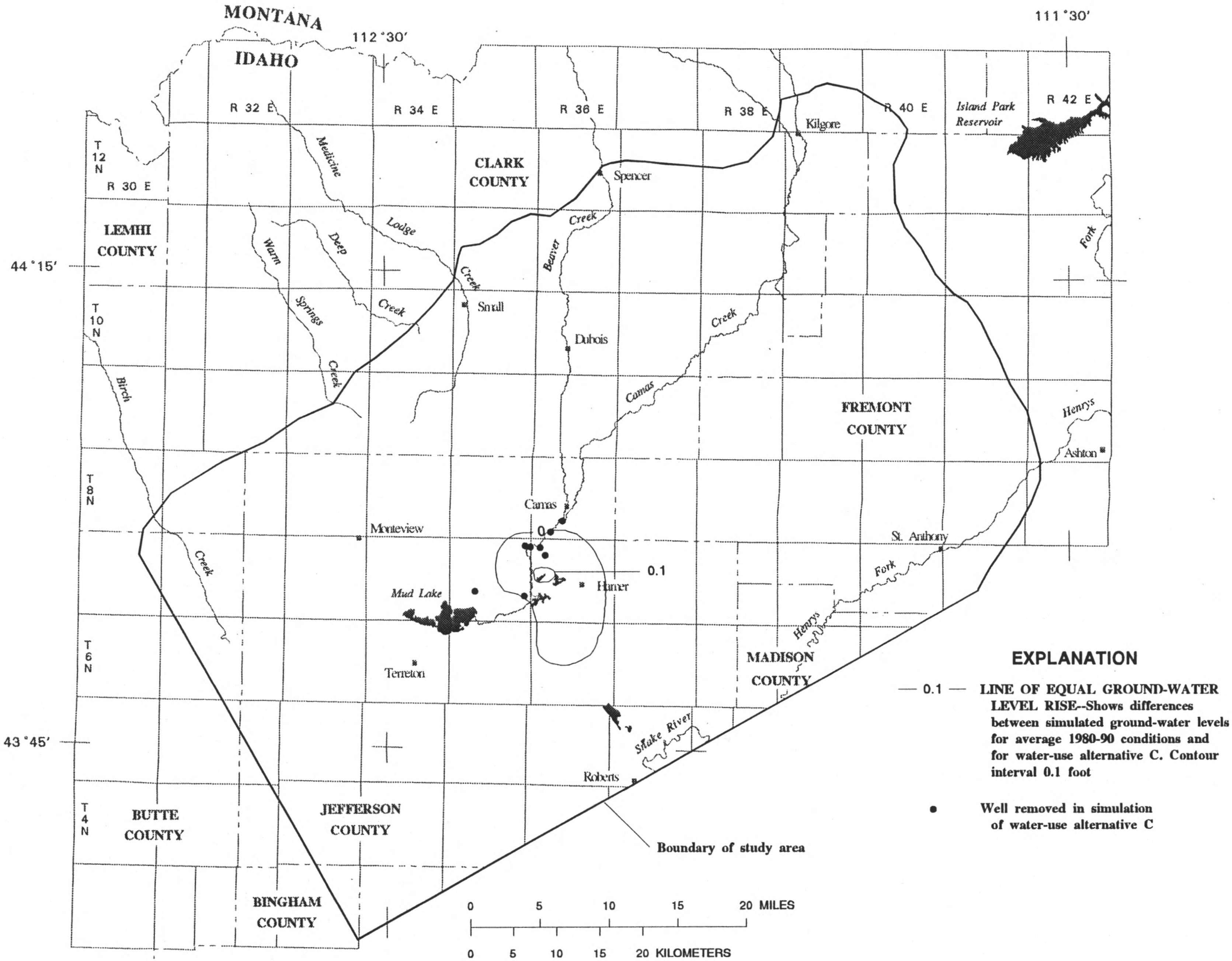


Figure 11. Differences between simulated ground-water levels for average 1980–90 conditions and for water-use alternative C.

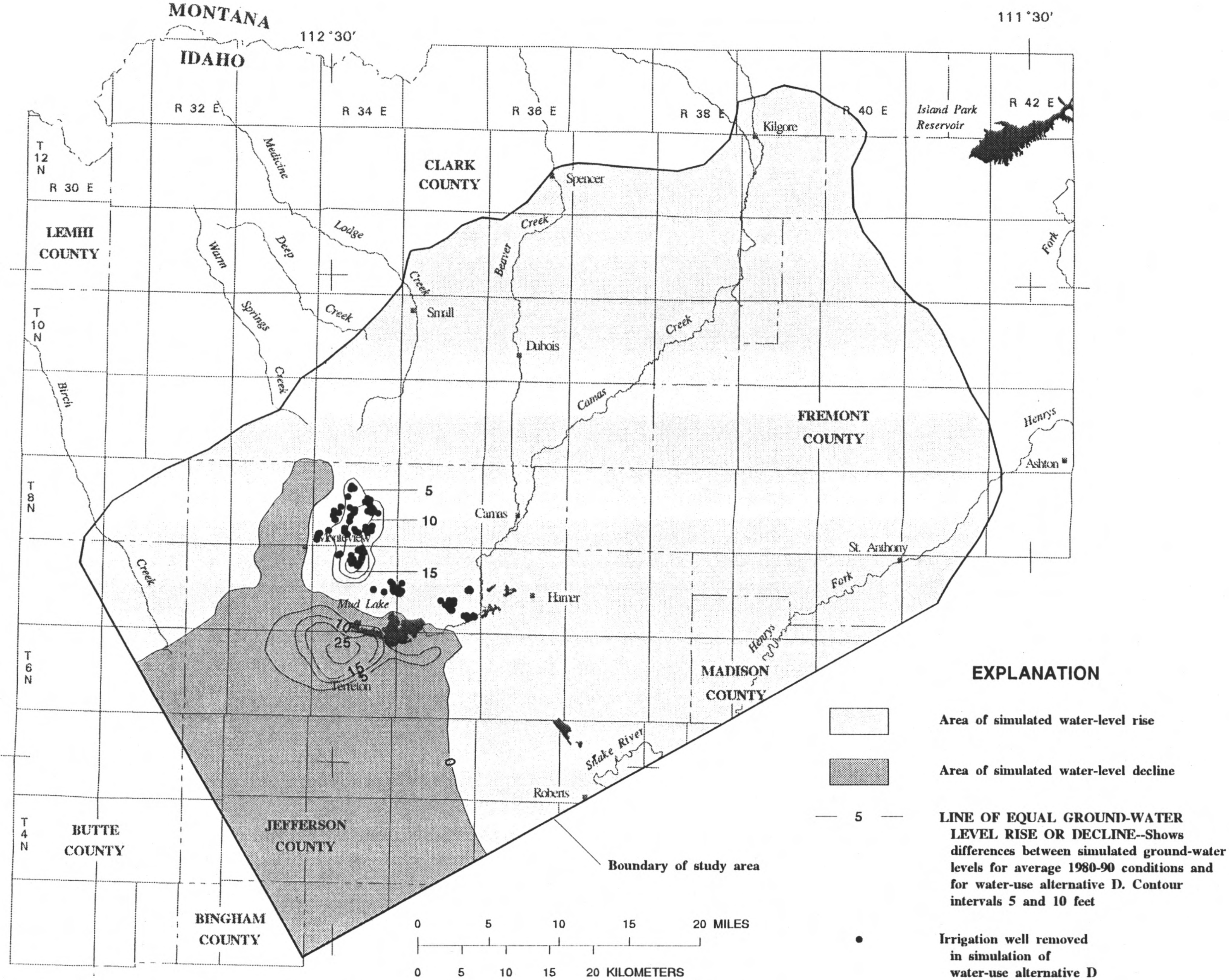


Figure 12. Differences between simulated ground-water levels for average 1980–90 conditions and for water-use alternative D.

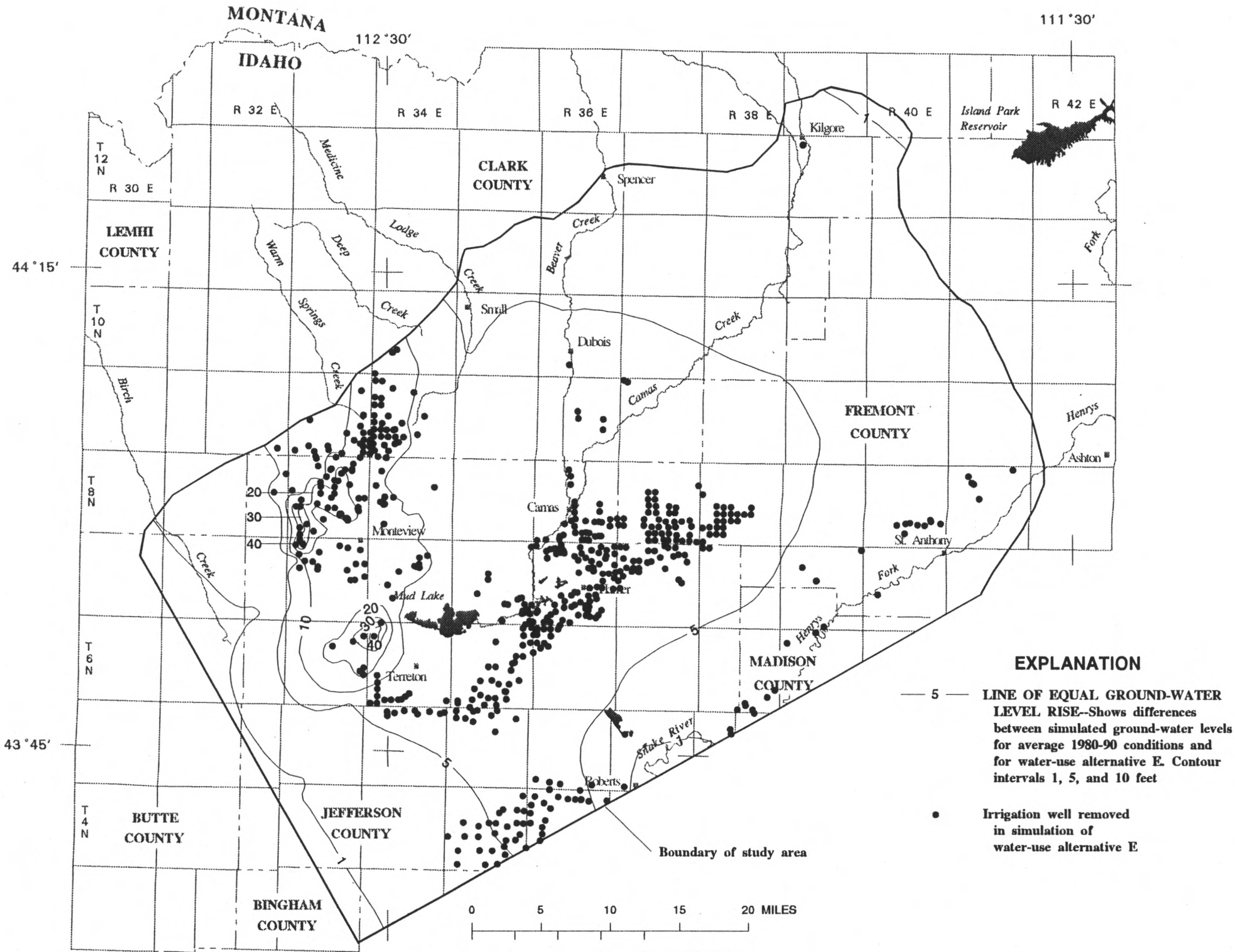


Figure 13. Differences between simulated ground-water levels for average 1980–90 conditions and for water-use alternative E.

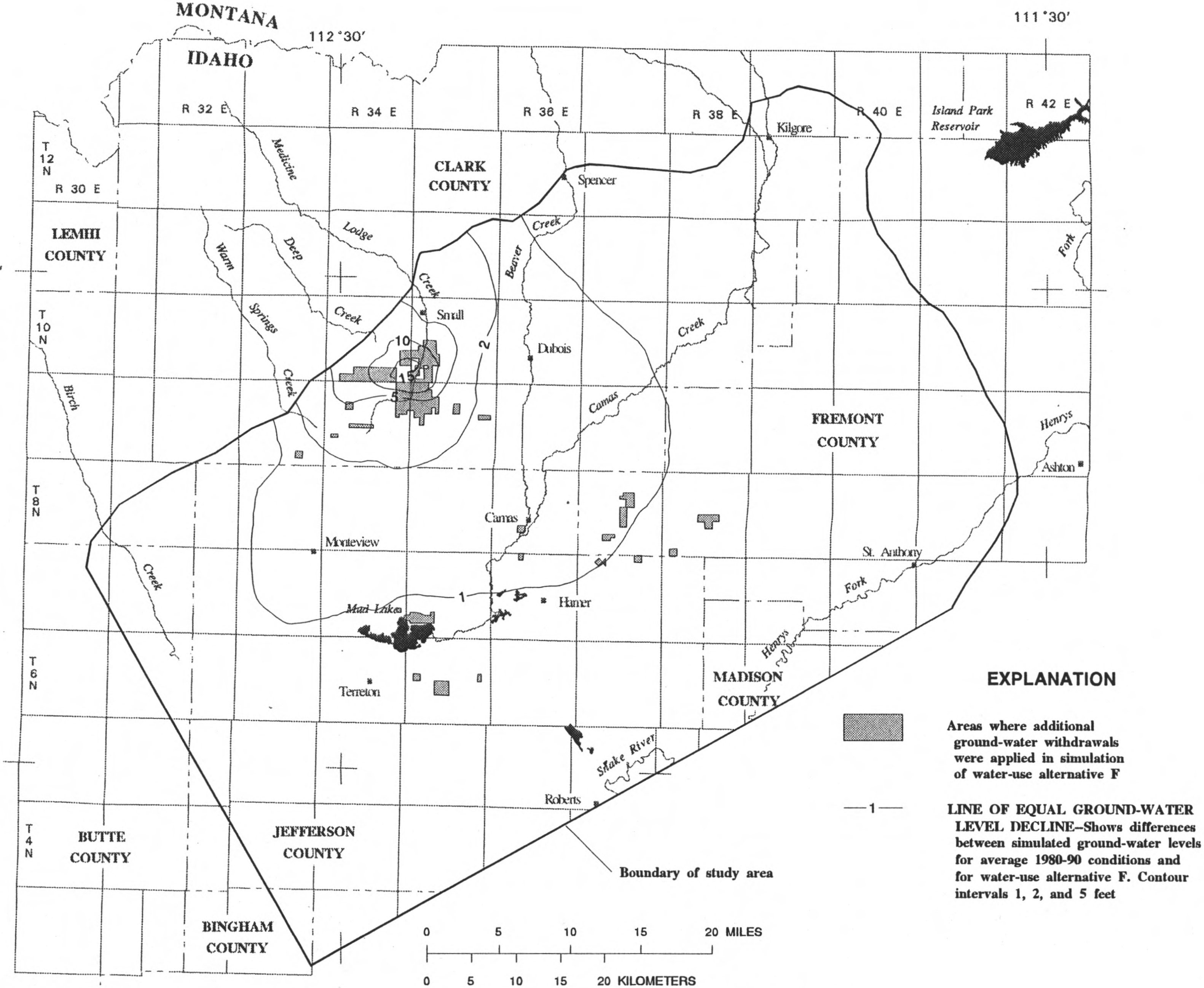


Figure 14. Differences between simulated ground-water levels for average 1980–90 conditions and for water-use alternative F.

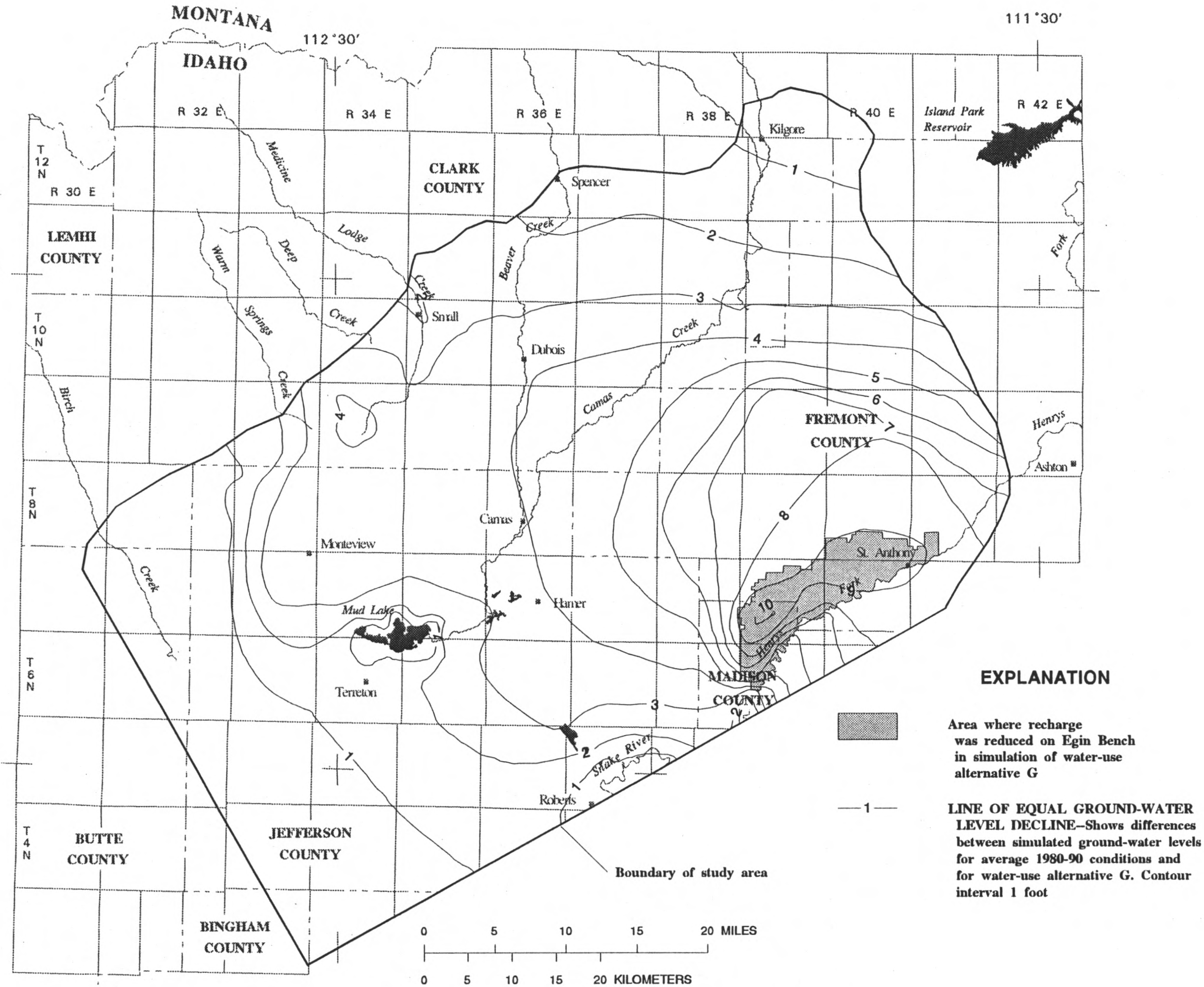


Figure 15. Differences between simulated ground-water levels for average 1980–90 conditions and for water-use alternative G.