ESTIMATING TRAVELTIMES OF BOATS THROUGH BALD EAGLE HABITAT ALONG THE SNAKE RIVER, NORTHWESTERN WYOMING, USING GEOGRAPHIC INFORMATION SYSTEM TECHNIQUES

By James F. Wilson, Jr. and Charles A. Eshelman

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CONVERSION FACTORS

Multiply inch-pound unit	By	To obtain metric unit
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per second (ft/s)	0.3048	meter per second
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

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ABSTRACT

Published equations for estimating traveltime of the leading edge of a solute were used to estimate traveltimes of boats on the Snake River between Jackson Lake Dam and Moose, Wyo., in Grand Teton National Park. The equations also were used to estimate traveltimes of boats through dimensionally defined areas of bald eagle habitat. Areas representing habitat near eagle nests and along the river were delineated as buffers using geographic information system (GIS) techniques. GIS techniques also were used to determine the intersection of the Snake River with other line features and with the habitat areas and to determine the reach lengths and channel slopes needed to estimate traveltimes. Hypothetical examples using 1986 float-trip data illustrate how the estimated traveltimes can be used to determine the cumulative daily percentage of time one or more boats are within each habitat area, which might be an indication of the potential disturbance of the eagles by float trips, according to wildlife biologists.

The traveltime-estimating techniques can be used to evaluate the passage of large numbers of free-floating boats through designated areas of interest along other rivers. Accuracy of results depends on use of a realistic distribution of starting times of boats. Use of GIS techniques in this investigation was limited, considering the potential analytical power available with GIS. However, as new information becomes available, the GIS can be modified and updated analyses performed. A variety of maps and diagrams was created using the GIS.

INTRODUCTION

During 1987 and 1988, personnel of the U.S. Geological Survey (USGS) and the National Park Service discussed possible investigations of mutual interest in Yellowstone and Grand Teton National Parks that would include applications of geographic information system (GIS) techniques. Earth-resources information is well suited to GIS analysis in combination with other spatially referenced resource information such as wildlife habitat, vegetation, and land use. At the suggestion of the staff of Grand Teton National Park, in 1988 the USGS selected and funded a brief investigation involving the passage of boats on float trips through bald eagle habitat along the Snake River in the park. Park managers and wildlife biologists are concerned about possible adverse effects of float trips, a popular recreational activity, on the bald eagles that nest and forage along the river. For example, the daily accumulation of time during which one or more boats is within a particular habitat area might be an indication of the potential disturbance of the eagles (M.T. Schroeder, National Park Service, written commun., 1988). The investigation was possible because the number of float trips was documented, specifically defined bald eagle nesting and foraging habitat along the river could be mapped using GIS techniques, USGS streamflow data were available, and a generalized equation for estimating traveltimes was considered to be applicable to the Snake River.

Purpose and Scope

This report describes procedures for estimating traveltimes of boats on float trips on the Snake River in Grand Teton National Park, and specifically, for estimating traveltimes of the boats though the riparian habitat of bald eagles. Hypothetical examples are used to illustrate how the estimated traveltimes can be used to determine the cumulative daily time one or more boats are within each habitat area. These procedures are applicable to other streams where float-trip reaches transect areas of wildlife habitat or areas classified for other uses. This report is not an assessment of the biologic effects of recreational boating on bald eagles.

Generalized equations for estimating traveltimes of solutes (Boning, 1974) are used in this report to estimate traveltimes of nonmotorized boats. Traveltime-discharge relations for selected subreaches of the Snake River were developed using Boning's equations, and channel lengths and slopes determined using GIS techniques. A procedure for onsite use of the traveltime-discharge relations, such as predicting the duration of a float trip, is included.

Use of GIS techniques is a major part of the analysis. A single line is used to represent the Snake River. GIS techniques are used to determine the spatial distribution of areas of eagle habitat, the points where the river intersects the habitat areas, and the lengths and slopes of river subreaches and segments of subreaches, and to create maps and diagrams.

Study Area

The study area is part of a broad, flat, glacial outwash plain called Jackson Hole, in Grand Teton National Park, northwestern Wyoming (fig. 1). The geomorphology of Jackson Hole and the Park are described by Love and Reed (1971). The high-relief topography surrounding the study area is illustrated in figure 2. The general study area comprises the areas covered by four USGS 7.5-minute topographic quadrangles (scale 1:24,000): Jenny Lake, Moran, Moose, and Shadow Mountain (fig. 1). The Snake River between Jackson Lake Dam and Park headquarters at Moose, Wyo. is the focus of the analyses (fig. 3).

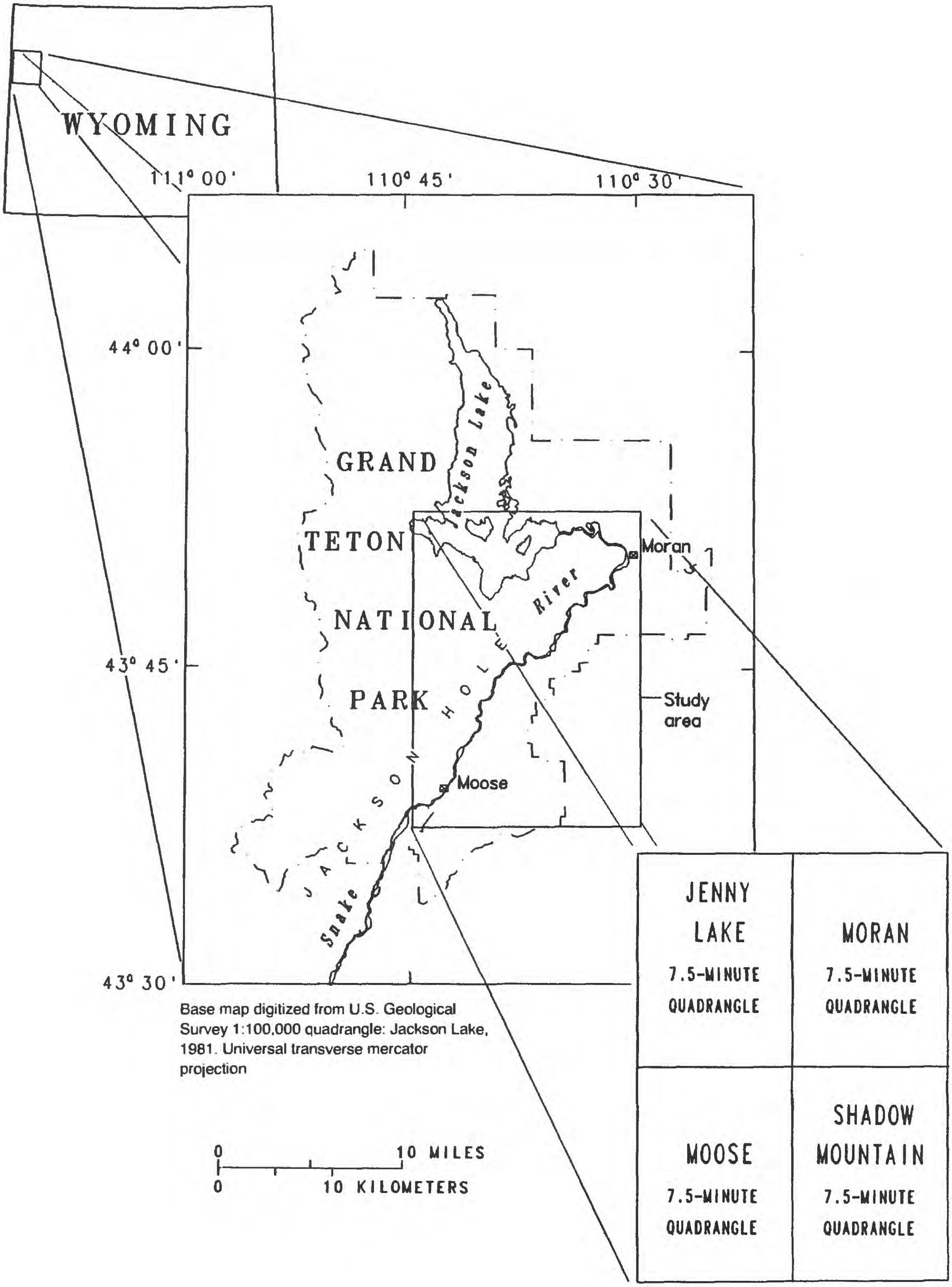


Figure 1.--Location of study area. The geographic information system (GIS) in this study is based on the indicated U.S. Geological Survey topographic quadrangles.

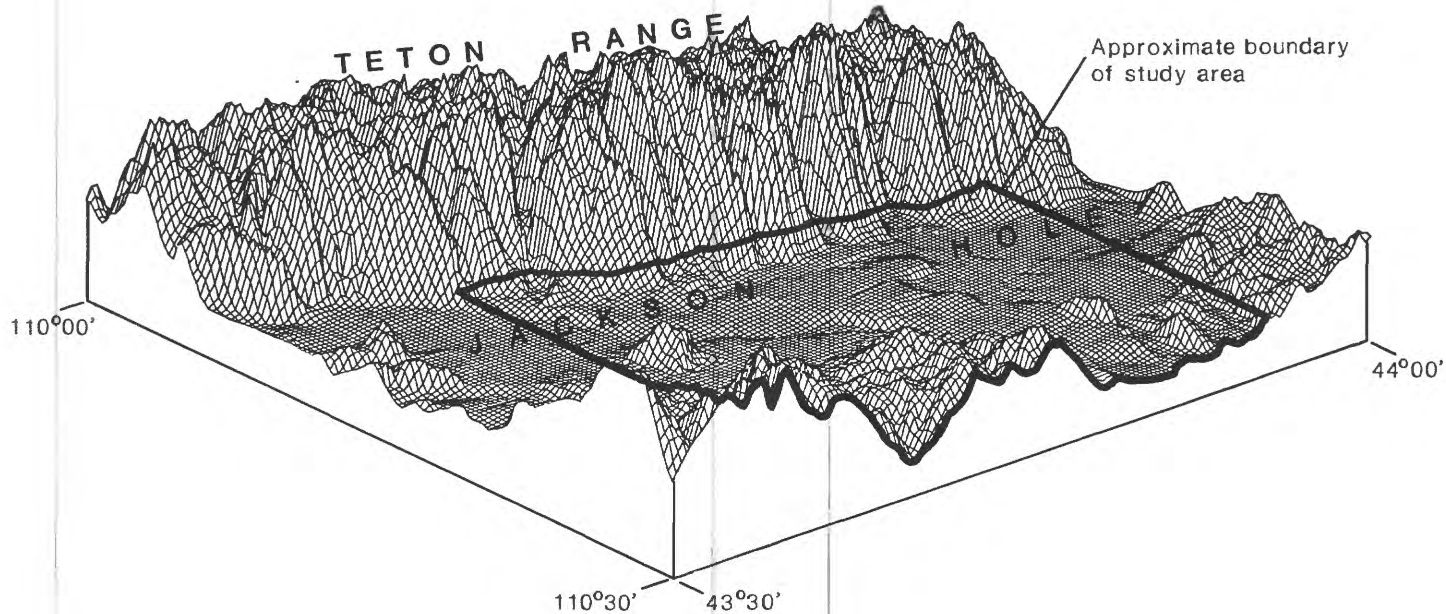
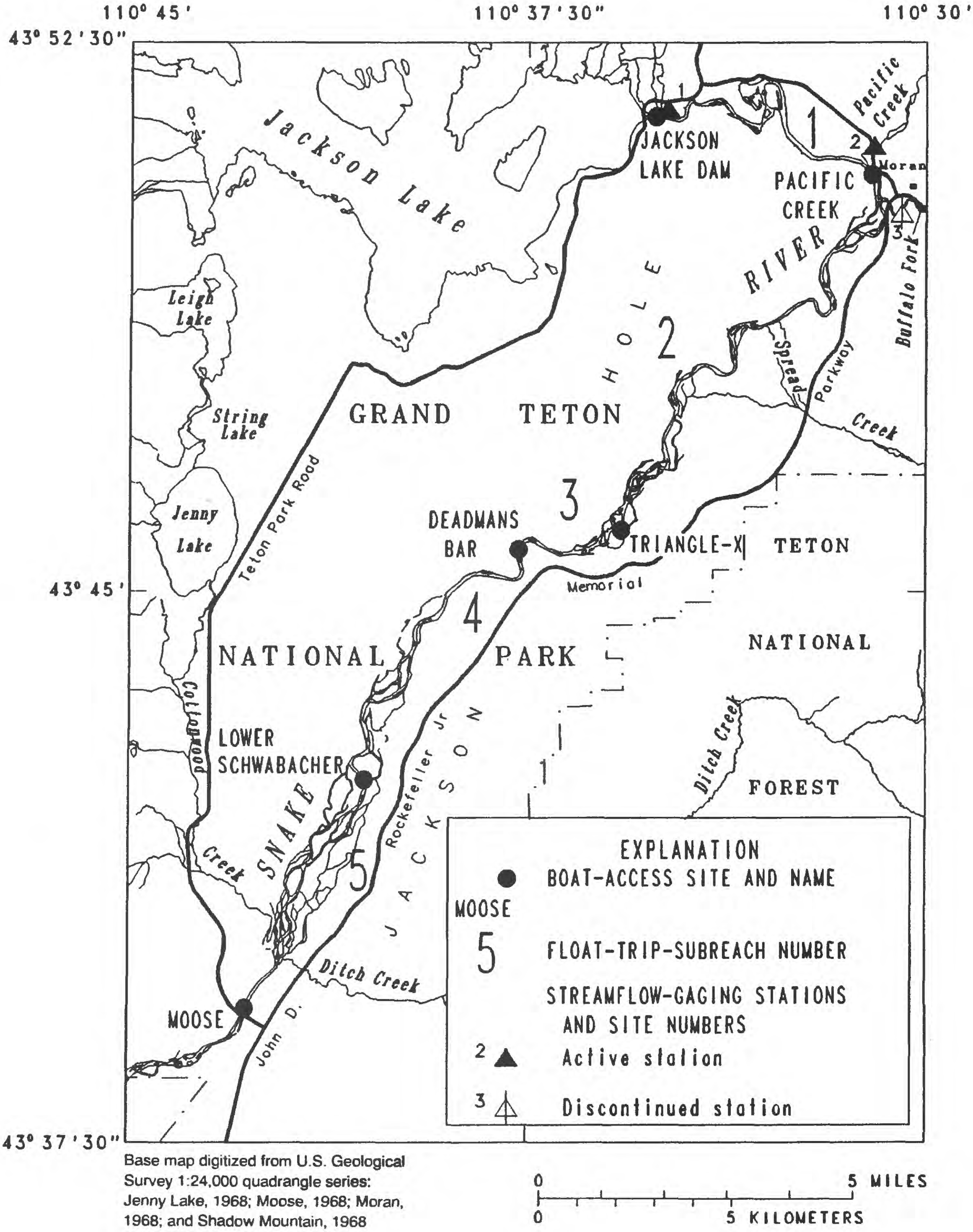


Figure 2.--Three-dimensional diagram of the land surface, Jackson Hole and vicinity, northwestern Wyoming. View is from southeast. The diagram was created from digital-elevation data for part of U.S. Geological Survey 1:250,000 quadrangle, Driggs, Ida.-Wyo., using geographic information system (GIS) software. Source of digital-elevation data: U.S. Defense Mapping Agency.



Base map digitized from U.S. Geological Survey 1:24,000 quadrangle series: Jenny Lake, 1968; Moose, 1968; Moran, 1968; and Shadow Mountain, 1968
Polyconic projection

Figure 3.--Location of boat-access sites, float-trip subreaches, and streamflow-gaging stations.

Acknowledgments

In 1987, Marshall A. Gingery, Assistant Superintendent for Research and Resource Management, Grand Teton National Park, suggested that GIS techniques might be useful for an investigation related to the aquatic environment of bald eagles. Mark T. Schroeder, a biologist on Gingery's staff, provided technical advice, float-trip data, and map overlays showing location of eagle nests and other features needed for the investigation. Seasonal park ranger George Montopoli and Prof. Donald A. Anderson, both of the Statistics Department, University of Wyoming, provided copies of their cummulative-effects model, user documentation, and final report to the National Park Service (Montopoli and Anderson, 1988). The cummulative-effects model is a statistical model based on the judgments of eagle experts regarding the temporary reduction in available bald eagle habitat as a result of river float trips and streambank usage. The model, which does not incorporate the locations of eagle nests, was not used with the GIS analysis; however, some of the information in the final report on the model was used for this report.

FLOAT TRIPS ON THE SNAKE RIVER

Float trips for fishing or to view the spectacular scenery and wildlife (including eagles) along the Snake River is a popular recreational activity in Grand Teton National Park. It is estimated that about one-half of the float trips are conducted by concessionaires and one-half by private parties (Montopoli and Anderson, 1988, p. 21). Almost any type of nonmotorized watercraft may be used. Inflatable rafts are popular; some are large enough to carry 20 people. The float-trip season in the Park generally is from late May through September, while flow in the Snake River is sustained by releases from Jackson Lake Dam for irrigation downstream. A few float trips are made at other times.

Concessionaire float-trip data reported to the National Park Service for 1986 were used in this investigation. The reported float-trip data are for the following five subreaches shown in figure 3:

1. Jackson Lake Dam to Pacific Creek
2. Pacific Creek to Triangle-X
3. Triangle-X to Deadmans Bar
4. Deadmans Bar to Lower Schwabacher
5. Lower Schwabacher to Moose

With the exception of Triangle-X, which is on private land, the boat-access sites at the ends of the subreaches are accessible by the general public.

The monthly distribution of the concessionaire float-trip data for 1986 is listed in table 1, and the same data aggregated by boat-access sites are listed in table 2. Each float trip was assumed to consist of a single boat; therefore, the number of trips equals the number of boats. The most popular put-in sites were Pacific Creek and Deadmans Bar, and nearly three-fourths of all trips ended at Moose (table 2). The data clearly indicate that the frequency-of-passage of boats would be greatest between Deadmans Bar and Moose (subreaches 4 and 5), because of the popularity of Deadmans Bar as a put-in site and the additional float trips beginning at Pacific Creek or Triangle-X

Table 1.--Monthly distribution of concessionaire float trips, 1986

[Source: M.T. Schroeder, National Park Service, written commun., 1988]

Float trip (sub-reach number)	Description	June	July	Aug.	Sept.	Total
1	Jackson Lake Dam to Pacific Creek	0	28	5	21	54
2	Pacific Creek to Triangle-X	41	69	54	17	181
2-3	Pacific Creek to Deadmans Bar	239	381	400	154	1,174
2-5	Pacific Creek to Moose	44	68	58	11	181
3-5	Triangle-X to Moose	12	17	14	1	44
4-5	Deadmans Bar to Moose	600	998	1,027	374	2,999
5	Lower Schwabacher to Moose[1]	190	313	343	10	856
	Totals	1,126	1,874	1,901	588	5,489

[1]Includes trips from Lower Schwabacher to sites downstream from Moose.

Table 2.--Monthly distribution of put-ins and take-outs for concessionaire float trips, 1986

[Source: M.T. Schroeder, National Park Service, written commun., 1988; --, not a take-out site (Jackson Lake Dam) or not a put-in site (Moose)]

Boat-access site	June		July		Aug.		Sept.	
	In	Out	In	Out	In	Out	In	Out
Jackson Lake Dam	0	--	28	--	5	--	21	--
Pacific Creek	324	0	518	28	512	5	182	21
Triangle-X	12	41	17	69	14	54	1	17
Deadmans Bar	600	239	998	381	1,027	400	374	154
Lower Schwabacher	190	0	313	0	343	0	10	0
Moose	--	846	--	1,396	--	1,442	--	396
Totals	1,126		1,874		1,901		588	

and ending at Moose. Disturbance by boats potentially would be greater for eagles that nest and forage along subreaches 4 and 5 than for eagles upstream from Deadmans Bar. Other than the sites listed in table 2, a few other boat-access sites are used occasionally, but these sites were not considered in this investigation. The data indicate only a few float trips in subreach 1 (table 1), so it was excluded from the analysis; however, there are eagle nests in the vicinity.

The monthly distribution of private float trips is unknown. In order to estimate the total number of concessionaire and private float trips, the numbers of float trips listed in tables 1 and 2 were doubled to account for private float trips.

The semimonthly float-trip data of Montopoli and Anderson (1988, p. 24, table VII) were reduced to ratios, and the ratios applied to the 1986 monthly data. The resulting semimonthly distribution of number of float trips (fig. 4) was used to determine the average number of boats per day for selected semimonthly periods in the traveltime analysis.

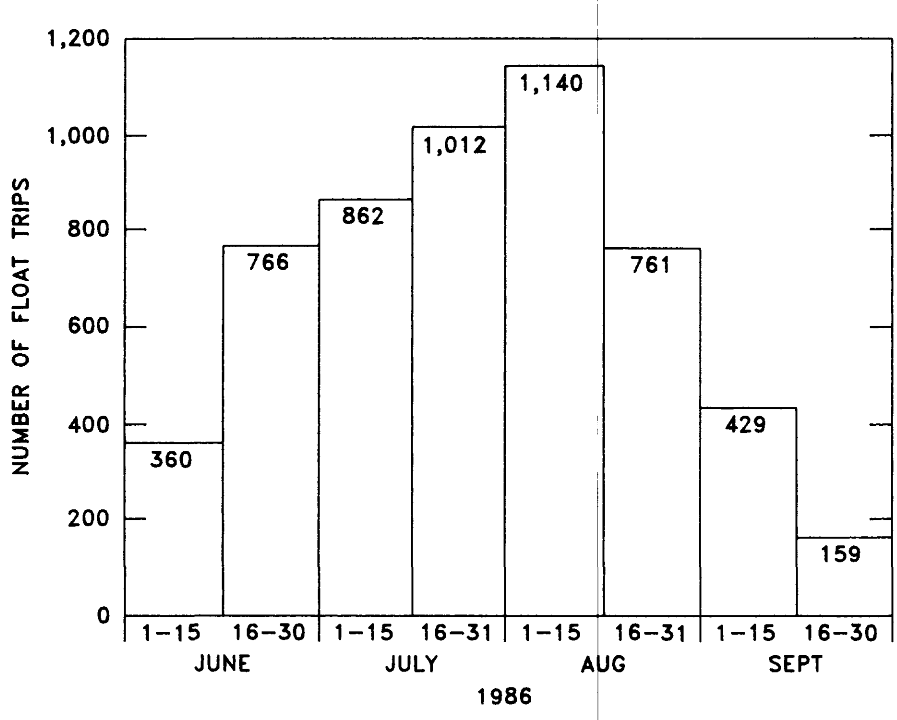


Figure 4.—Estimated semimonthly distribution of concessionaire float trips, 1986. Monthly data from M.T. Schroeder, National Park Service (written commun., 1988) modified on the basis of semimonthly data from Montopoli and Anderson (1988, p. 24, table VII).

Montopoli and Anderson (1988, p. 21, table V) also report a diurnal variation in the number of boats floating the river. Their diurnal distribution, based on boat counts for 2-hour intervals at observation sites in subreaches 2 and 5 (fig. 3) during July and August 1987, are expressed as percentages of the average daily total number of boats launched as follows:

Time (hours)	0800-1000	1000-1200	1200-1400	1400-1600	1600-1800
Percentage	14.7	23.5	25.9	21.8	14.1

These percentages were used in this investigation to estimate average time intervals between float-trip starts, because a more realistic distribution of starting times was not available. Subsequent calculations indicated that all float trips ended by 2000 hours.

ESTIMATING TRAVELTIMES OF NONMOTORIZED BOATS

Traveltime of the water or of floating objects in a stream is calculated from stream velocity, which varies with stream discharge. To estimate traveltime, discharge must be known or estimated. Discharges in the Snake River and major tributaries in the study area are well-documented by data collected at long-term USGS streamflow-gaging stations. Published regression equations (Boning, 1974) are available for estimating traveltimes for specified discharges.

Stream Discharge

Most of the discharge in the Snake River in the study area is water released from Jackson Lake Dam, constructed at the outflow of Jackson Lake in 1906. The storage created by the dam is used for irrigation in the Snake River valley in Idaho (U.S. Bureau of Reclamation, 1984, p. 13). Other uses include flood control and recreation. Because of releases from the dam during the summer irrigation season, discharge in the river usually is ideal for float trips from May or June through September. Outflows from the lake and dam have been monitored since water year 1904 at USGS streamflow-gaging station 13011000, Snake River near Moran, 1,000 ft downstream from the dam (site 1, fig. 3).

The river channel is braided in many places between the dam and Moose. The discharge in the river is distributed through the side channels in varying amounts. During the float-trip season, some of the side channels carry enough of the total discharge to serve as alternate routes for boats. For purposes of estimating traveltimes, a single route through the braided reaches was assumed. The effect, if any, of braiding on the discharge used to estimate traveltimes is not known.

There are few major tributaries to affect traveltimes in the Snake River in the study area. Pacific Creek, about 4 river miles downstream from Jackson Lake Dam, and Buffalo Fork, less than 1 river mile farther, contribute discharges large enough to affect estimates of velocities and traveltimes in the river. USGS streamflow-gaging station 13011500, Pacific Creek at Moran, 0.5 river mile upstream from the Snake River (site 2, fig. 3), was operated during water years 1945-75 and 1979 to date (table 3). Station 13011900, Buffalo Fork above Lava Creek, near Moran, 4.0 river miles upstream from the Snake River (upstream of the area shown in fig. 3), has been operating since water year 1966. However, during water years 1945-60, station 13012000, Buffalo Fork near Moran, was operated at a site 0.5 river mile upstream from the Snake River (site 3, fig. 3). Discharges for the discontinued station on Buffalo Fork (site 3) were used in this investigation because the station is closer to the mouth of Buffalo Fork than the station above Lava Creek.

The only other perennial tributaries of consequence are Spread, Ditch, and Cottonwood Creeks (fig. 3). None has been gaged, so the discharge contributed from these tributaries to the discharge in the Snake River could not be considered in the analysis. Effects of Ditch Creek and Cottonwood Creek would be minor because they join the Snake River near the downstream end of the study reach.

Table 3.--Mean monthly discharge from May through September at streamflow-gaging stations, through water year 1984

[Source: Peterson (1988)]

Site number (fig. 3)	Station name, number, and period of record (water years)	Drainage area (square miles)	Mean monthly discharge (cubic feet per second)				
			May	June	July	Aug.	Sept.
1	Snake River near Moran[1] (13011000) 1904-84	807	1,380	3,420	4,250	3,680	1,930
2	Pacific Creek at Moran (13011500) 1945-75, 1979-84	169	923	1,310	377	102	73
—	Buffalo Fork above Lava Creek, near Moran (13011900) 1966-84	323	974	2,410	1,540	462	280
3	Buffalo Fork near Moran (13012000) 1945-60	378	1,280	2,430	1,460	460	274

[1]Discharge at station is controlled by releases from Jackson Lake Dam.

Generally, discharge of the Snake River is greater than the minimum needed for float trips from May through September. That minimum discharge probably is between 500 and 1,000 ft^3/s. The distribution of mean monthly discharges of the Snake River (table 3 and fig. 5) indicates how releases from Jackson Lake Dam sustain stream discharges suitable for float trips from May through September, which contrasts with Pacific Creek and Buffalo Fork, in which most of the annual discharge occurs during the snowmelt season from May through July (fig. 5).

The streamflow-gaging station on the Snake River near the dam (site 1, fig. 3) is a logical index station to use for relating traveltimes to discharges in the Snake River. However, discharge at the index station is not a consistent indicator of discharge in the subreaches downstream from Pacific Creek and Buffalo Fork. It is necessary to adjust the discharge used to estimate velocity and traveltime in the Snake River by adding the estimated discharge from the two major tributaries, Pacific Creek and Buffalo Fork, to the discharge at the index station. As indicated in figure 5, discharge of those streams varies considerably during the May-September float-trip season.

Traveltime Equations

Traveltimes of boats on float trips were estimated using generalized equations previously developed for traveltimes of solutes in streams. A simplifying assumption used in this investigation is that, without the effects of wind, the velocities and traveltimes of freely floating objects such as boats are about the same as the velocities and traveltimes of the leading edges of solute plumes. It is also assumed that, during float trips, boats move with the water, without slowing down or stopping.

Boning (1974) used data from measurements of traveltime of water-soluble dyes in more than 300 streams throughout the United States to develop regression equations for estimating solute velocity, traveltime, and dispersion characteristics for three types of stream reach: (1) Channel-controlled, (2) pool-and-riffle, and (3) lock-and-dam. The equations for estimating the velocity and traveltime of the leading edge of a solute in a channel-controlled reach were selected as being most applicable for this investigation. The equations (Boning, 1974, p. 498) are as follows:

$$V_1 = 2.86\ Q^{0.27}\ S^{0.28}; \text{ and} \qquad (1)$$

$$T_1 = 1.467\ \frac{L}{V_1}\ , \qquad (2)$$

where V_1 is velocity of leading edge of solute, in feet per second;
Q is stream discharge, in cubic feet per second;
S is channel slope, in foot per foot;
T_1 is traveltime of leading edge of solute, in hours; and
L is length of reach, in river miles.

The standard error of estimate for equation 1 is 26 percent.

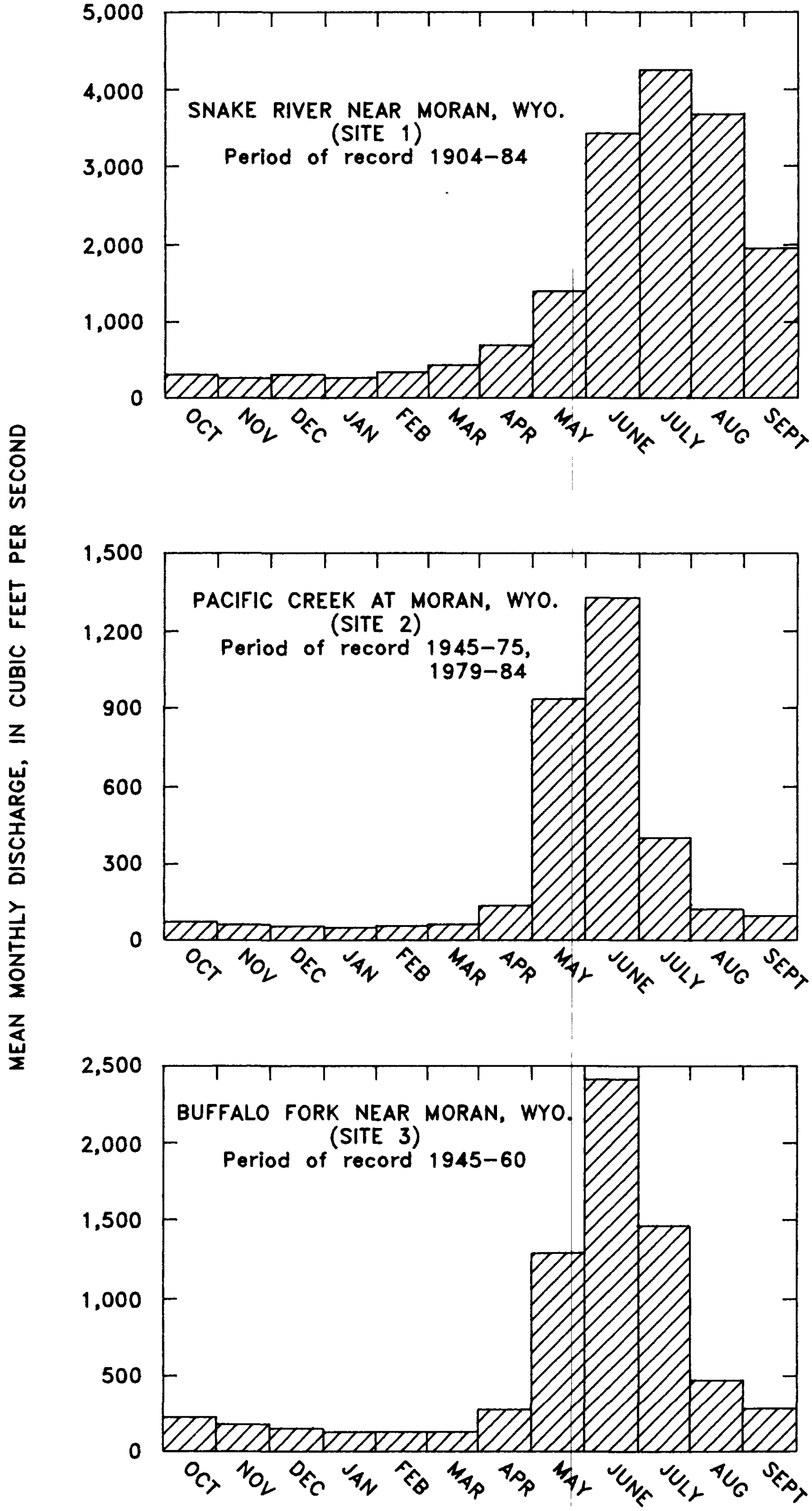


Figure 5.--Distribution of mean monthly discharge at streamflow-gaging stations. From Peterson (1988, p.195, 197, 201).

For a given subreach of stream, the channel slope and length are constants, and equations 1 and 2 can be combined to express traveltime as a function of stream discharge as follows:

$$T_1 = k\ Q^{-0.27}, \tag{3}$$

where $k = 0.513\ L\ S^{-0.28}$.

The constant k can be stored in the GIS data base as an attribute of each arc representing a subreach or segment of a subreach and used to compute traveltimes for specified discharges with a GIS program (macro).

Even if the estimated traveltimes accurately represent those of freely floating objects, the estimated traveltimes are only approximations when applied to float trips. Other variables affect the actual traveltime of a boat: the velocity and direction of wind; the route traveled through the braided channel; paddling with or against the current; or stopping along the way. These variables could not be accounted for in the estimates of traveltimes.

Traveltime-discharge curves for selected float-trips reaches (fig. 6) were prepared using equation 3. Channel slopes and lengths of the subreaches were computed using GIS techniques. The discharge used in equation 3 must be the discharge downstream from Buffalo Fork; that is, the combined discharges of the Snake River, Pacific Creek, and Buffalo Fork. The instantaneous discharge in the Snake River near the dam (site 1) can be specified for analytical purposes, or it can be determined onsite to plan a float trip. Onsite, the discharge of the Snake River near the dam can be determined by reading the staff gage at the station and applying the stage-discharge relation for the station (available from the U.S. Geological Survey office in Idaho Falls, Ida.). The appropriate mean monthly discharges (table 3) for Pacific Creek (site 2) and Buffalo Fork (site 3) can be used as approximations of the inflow from the two tributaries.

After adding estimated discharges from Pacific Creek and Buffalo Fork to the specified or actual instantaneous discharge in the Snake River near the dam, equation 3 or the curves in figure 6 are used to estimate the traveltime. For example, if during June the specified or actual instantaneous discharge at the dam is 5,000 ft^3/s, estimates of about 1,300 ft^3/s for Pacific Creek and about 2,400 ft^3/s for Buffalo Fork (table 3) would be added, for a total of 8,700 ft^3/s. The estimated traveltime between Pacific Creek and Moose (subreaches 2-5) for a discharge of 8,700 ft^3/s is about 5.25 hours (fig. 6).

To test the sensitivity of estimated traveltimes in the Snake River (using eq. 3) to the discharges of Pacific Creek and Buffalo Fork, the preceding example was recalculated using the minimum and maximum recorded June discharges of the two tributaries (Peterson, 1988, p. 196, 200) and the specified instantaneous discharge of 5,000 ft^3/s for the Snake River near the dam. Through water year 1984, the minimum recorded June discharge was 469 ft^3/s for Pacific Creek and 1,590 ft^3/s for Buffalo Fork; the total discharge of the Snake River would be 7,060 ft^3/s (rounded), and the traveltime between Pacific Creek and Moose about 5.5 hours (fig. 6). Maximum recorded June discharges were 2,380 ft^3/s for Pacific Creek and 3,590 ft^3/s for Buffalo

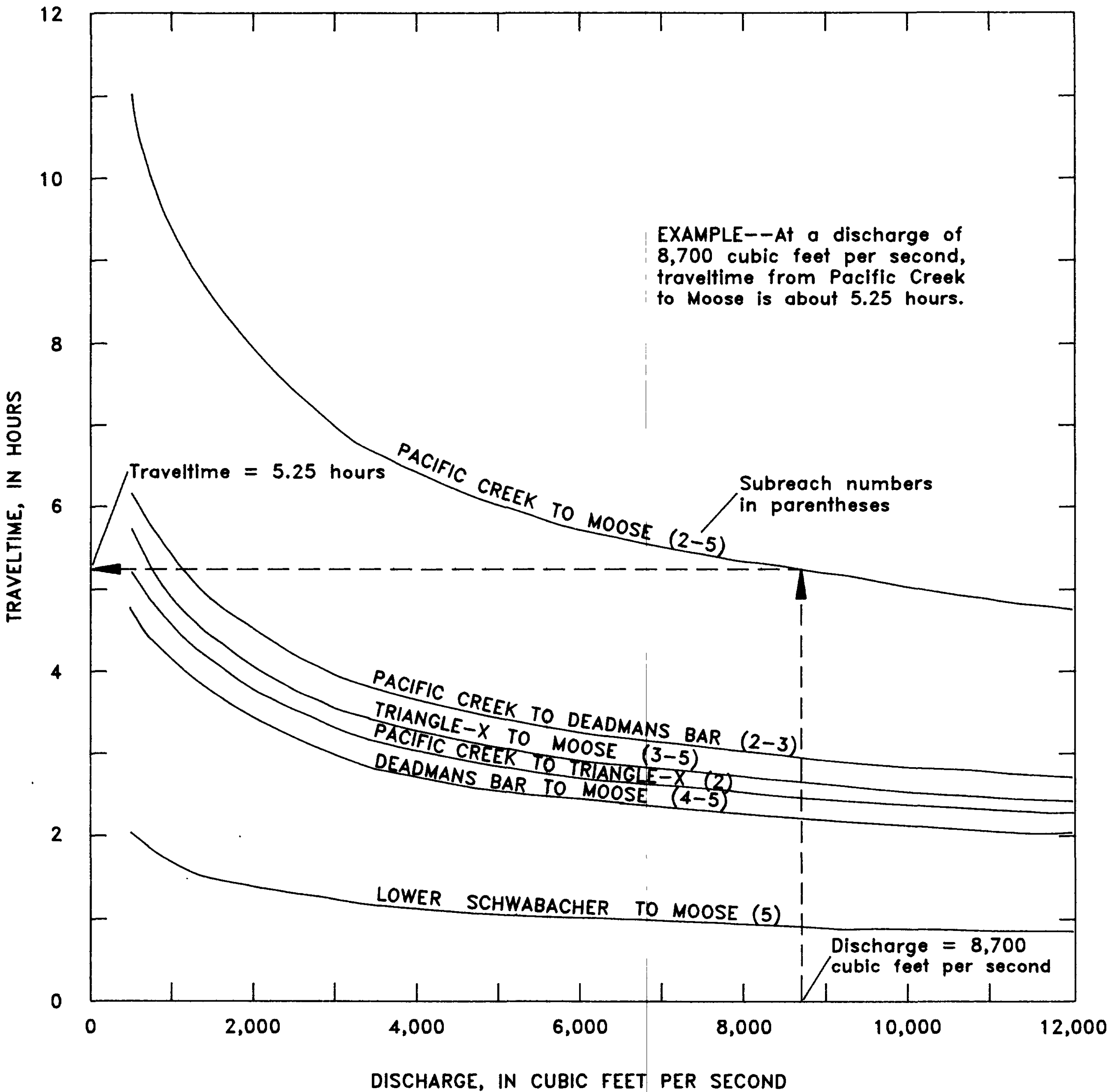


Figure 6.--Relations of estimated traveltime of boats to discharge in the Snake River downstream from Buffalo Fork for reaches commonly used for float trips. Calculated from equation 3.

Fork; the total for the river would be about 11,000 ft^3/s and the estimated traveltime about 4.9 hours (fig. 6). Compared to the traveltime estimated using mean monthly discharges, the traveltime using minimum monthly discharges is about 0.25 hour (15 minutes) longer, and the traveltime using maximum monthly discharges is about 0.35 hour (21 minutes, or about 1 minute per river mile) shorter. Such differences indicate that the mean monthly discharges listed in table 3 for Pacific Creek and Buffalo Fork are adequate approximations of the instantaneous discharges for estimating traveltimes in the Snake River.

The Park Service provided a tabulation of traveltimes for selected discharges in the reach between Pacific Creek and Moose (M.T. Schroeder, written commun., 1988), for comparison with the estimates made using equation 3. These are shown in figure 7. The tabulation was prepared by the River Patrol; it is not known how the information was collected. If the discharges, which most likely represent flow at the dam, are increased to account for the discharge from Pacific Creek and Buffalo Fork, the River Patrol curve is shifted substantially toward the curve based on equation 3. Even without such an adjustment, most of the River Patrol curve fits within the 26-percent standard error of estimate for the curve based on equation 3 (fig. 7).

Following a brief discussion of eagle-habitat zones, the remainder of this report describes how equation 3 was used to estimate traveltimes of nonmotorized boats through habitat zones in subreaches 2 through 5. Reach lengths and channel slopes for use in equation 3 were determined using GIS techniques.

BALD EAGLE HABITAT ZONES

During most years, several pairs of bald eagles nest along the Snake River between Jackson Lake Dam and Moose (fig. 3). The nests are constructed in large trees; most are within a few hundred feet of the river. The trout in this part of the river provide most of the eagles' food (as well as that of competing ospreys) during the summer. The fishery that attracts the eagles to the river also attracts humans.

The Greater Yellowstone Ecosystem (GYE) Bald Eagle Working Group has recommended three zones for interim management of bald eagle breeding territories. The following descriptions of the eagle-management zones are from the GYE Bald Eagle Management Plan prepared by the working group (M.T. Schroeder, written commun., 1988):

Zone I	Occupied nesting zone--humans generally excluded
Zone II	Primary-use area--limited use by humans
Zone III	Home range--human developments severely limited.

The definitions of the eagle-management zones, referred to as habitat zones in this report, are based on numerous studies by eagle biologists in the GYE and elsewhere. Dimensions of the habitat zones are defined in metric units, which are used in this report. Zone I is the area within 400 meters (about 1,300 ft) of an active or alternate nest; human intrusion into this zone may cause great stress to the eagles, including inattentiveness to their

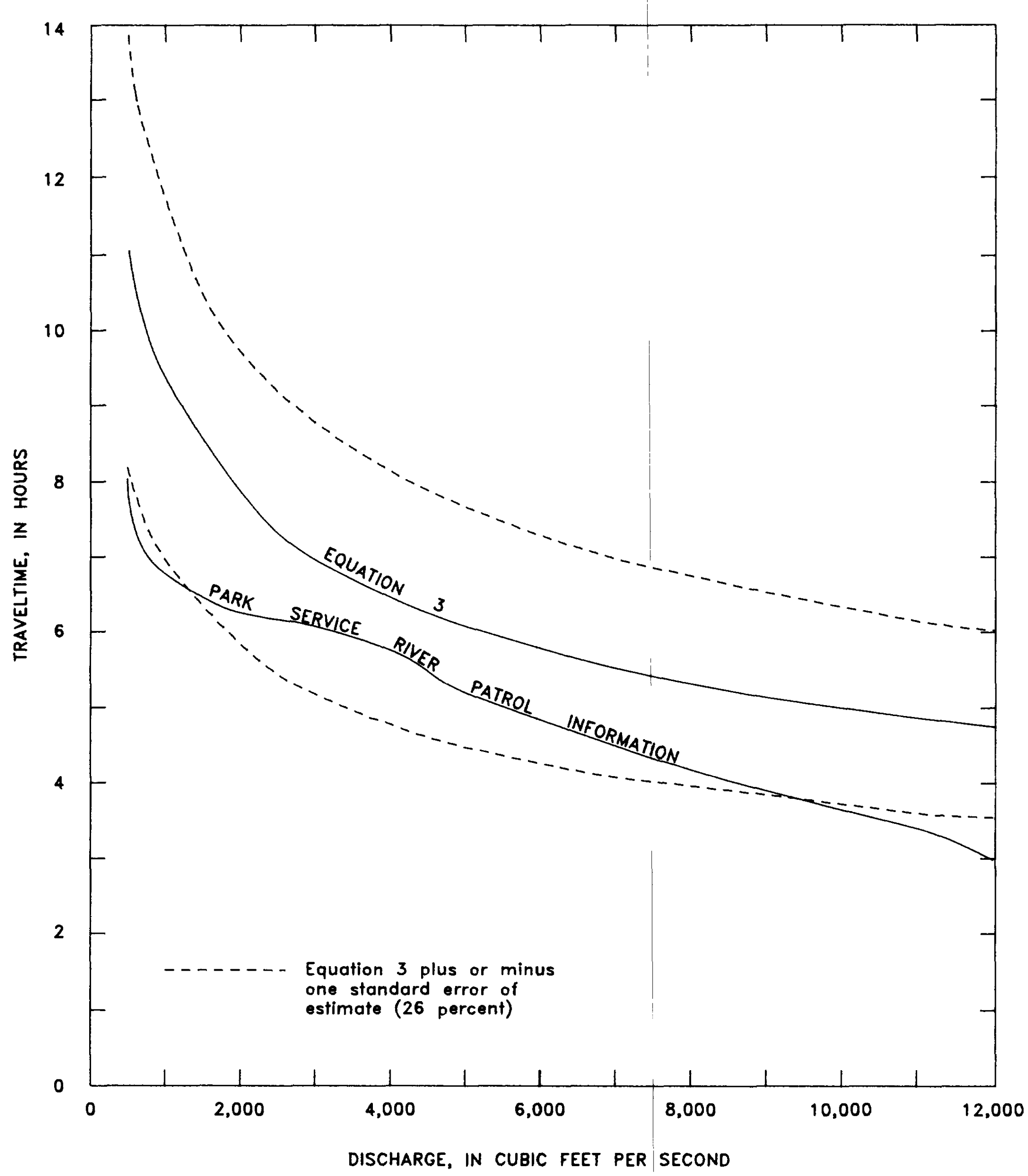


Figure 7.--Traveltime-discharge curves derived from equation 3 and from National Park Service River Patrol information. Traveltimes are for the reach between Pacific Creek and Moose. Discharges for equation 3 are for the Snake River downstream from Buffalo Fork. Discharges for River Patrol may be for the river at Jackson Lake Dam (site 1).

eggs or young. Zone II is the area within 800 meters (about 2,600 ft) of an active or alternate nest; eagles defend this zone against other eagles, and only limited human intrusion is advised. Zone III, defined on the basis of limited data, is the area within 400 meters (about 1,300 ft) of foraging habitat that also is within 4 kilometers (about 2.5 mi) of a nest; human developments are to be severely limited within this zone. The Snake River is the only foraging habitat considered in this investigation. As described in the next section, the habitat zones can be delineated in a GIS for analysis of traveltimes of boats passing through them. The zones are shown in figure 8.

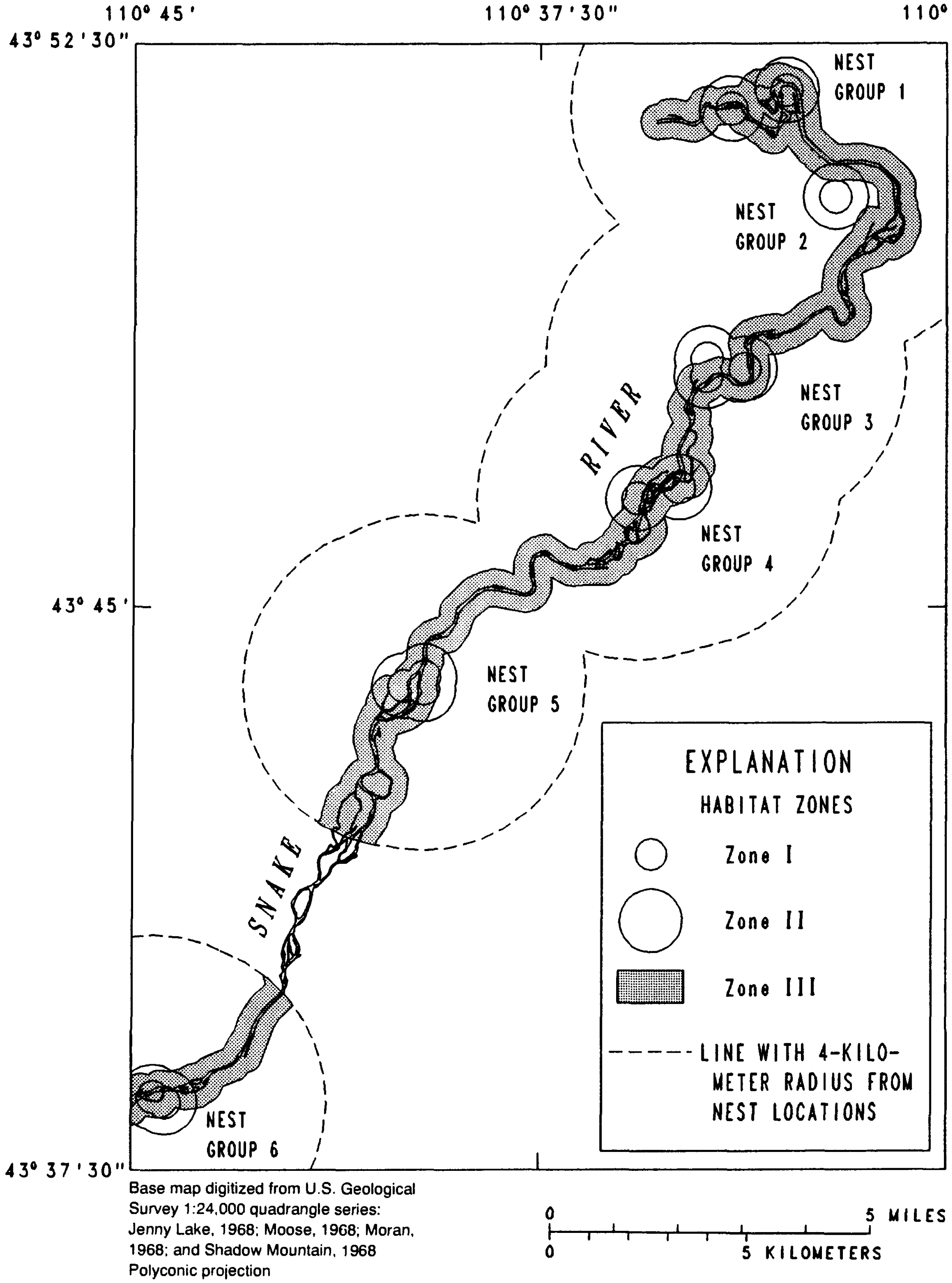


Figure 8.--Configuration of habitat zones delineated using geographic information system (GIS) techniques.

ESTIMATING TRAVELTIMES OF BOATS THROUGH HABITAT ZONES

Estimated traveltimes can be used to determine the cumulative daily time one or more boats are within each habitat area. The information needed for estimating traveltimes includes the length and slope of the river channel in each habitat area. GIS techniques were used to determine this information.

Use of Geographic Information System (GIS) Techniques

The GIS was created by compiling selected thematic information for each of the four USGS 7.5-minute topographic quadrangles shown in figure 1. Each quadrangle was treated as a separate module consisting of several data layers called coverages, that consist of digitized map features and associated tables of attributes for individual types of data, such as water bodies. For each type of data, the quadrangle coverages were joined to form a study-area coverage for analysis and display. Base-map information was digitized from mylar color-separates of the quadrangles. Additional features, such as location of eagle nests, were delineated on punch-registered mylar for digitizing. The coverages were created and stored in the polyconic map projection, which was the map projection of the topographic quadrangles. Coordinates and distances were stored in meters and converted to inch-pound units as needed in the analyses.

Some coverages were digitized for use with GIS analytical techniques and some only for reference or background use in map displays. Additional coverages were created during the analysis. The digitized coverages are listed in table 4. Coverages created during the analysis are discussed later.

Table 4.--Digitized coverages for the geographic information system (GIS) data base

Coverage name	Type	Content
NESTS	Point	Eagle nests; streamflow-gaging stations
WATER	Polygon	Water bodies (Snake River; Buffalo Fork; lakes and ponds)
FLOWPATH	Line	"Centerline" of Snake River
CONTOURS	Line	Topographic contour crossings of Snake River
SECTIONS	Line	Lines across river at ends of float-trip subreaches
STREAMS	Line	Perennial and ephemeral streams
ROADS	Line	Roads by type; trails; Park boundary
PULLOUTS	Polygon	Areas of boat-access sites, by type
BOUNDARY	Line	Topographic-quadrangle boundaries

The GIS software used was ARC/INFO[1]. The GIS techniques are described in a series of software manuals (Environmental Systems Research Institute, Inc., 1987a, 1987b, 1987c, 1989). In the discussion that follows, coverage names are given in capital letters.

Delineation of Habitat Zones

GIS techniques were used to delineate the three habitat zones previously described. A buffer procedure in the software creates a polygon around a specified feature in a coverage. The dimensions of the polygon are defined by a user-specified distance from the feature.

Separate buffers were created around each nest (point feature) for zone I (400-meter radius), zone II (800-meter radius), and the maximum limit of zone III (4-kilometer radius). Where circles from adjacent nests overlap, the software eliminates lines within the common areas. The habitat zones are shown in figure 8. The buffer coverages for the nests were named NESTBUF400, NESTBUF800, and NESTBUF4K. The zone type (I, II, or III) was stored in the feature-attribute table for each buffer, for use in analysis of intersections of the zones with the river. NESTBUF400, NESTBUF800, and NESTBUF4K were combined into a single coverage, NESTZONES, in two steps using the software's union procedure, as indicated in the left part of figure 9.

The 400-meter zone on both sides of the Snake River (polygon feature) also was delineated using the buffer procedure (figs. 8 and 9). This coverage, named WATERBUF, was used both for display purposes and for additional GIS analyses. The area common to NESTBUF4K and WATERBUF is zone III (fig. 8).

Subdivision of Flowpath

To delineate distances along the Snake River, which had been digitized as a polygon coverage to show details of channel braiding on maps created later, a line coverage called FLOWPATH was digitized. FLOWPATH is a single line (arc) representing the Snake River between Jackson Lake Dam and the downstream edge of the study area. Because it is an assumed route through the braided channels, FLOWPATH can only approximate the path boats might follow, as the actual paths taken are at the discretion of the boaters. GIS techniques were applied to FLOWPATH to subdivide it for three purposes: (1) Location of intersections of the river, as represented by FLOWPATH, with the boundaries of habitat zones; (2) delineation of float-trip subreaches and determination of their lengths; and (3) determination of channel slope for each subreach.

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[1]The use of product names in this report is for identification purposes only, and does not constitute endorsement by the U.S. Geological Survey.

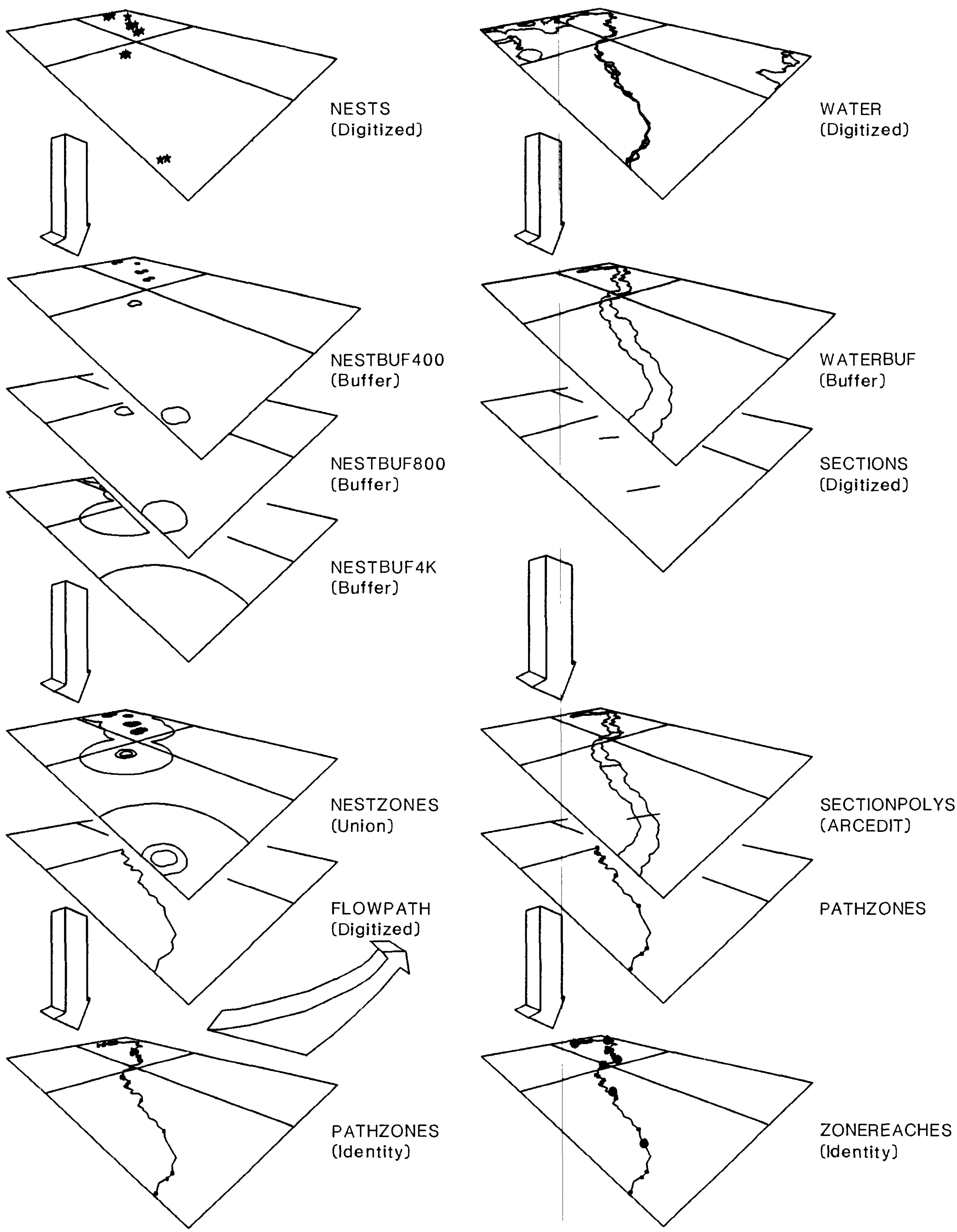


Figure 9.--Schematic diagram of selected coverages created using geographic information system (GIS) techniques. Technique used to create coverage is in parentheses. The perspective view is from southwest.

Habitat-zone intersections

The first subdivision of FLOWPATH located the intersection of the Snake River with the boundaries of the habitat zones. These intersections, in combination with ends of subreaches, define the lengths of stream segments (arcs) needed for traveltime calculations.

GIS techniques were used to combine the previously described coverage called NESTZONES with FLOWPATH to produce a line coverage called PATHZONES (fig. 9, lower left). The nodes in PATHZONES represent points along the river where a boat enters or leaves a habitat zone. The software automatically assigned the appropriate zone type (I, II, or III) from NESTZONES to each arc (line segment) between the nodes in PATHZONES.

Float-trip subreaches

The second subdivision of FLOWPATH was by float-trip subreach. The buffer on both sides of the Snake River (WATERBUF) was combined with a line coverage called SECTIONS into a coverage called SECTIONPOLYS (fig. 9) using the ARCEDIT subsystem of ARC/INFO. SECTIONS is a set of digitized lines across the river representing the ends of the subreaches, which are boat-access sites. Subreach numbers were stored in the attribute file of SECTIONPOLYS. GIS techniques were used to create nodes at the ends of the five subreaches along FLOWPATH with SECTIONPOLYS. The resulting coverage, called PATHREACHES (not shown in fig. 9) contains a line segment (arc) for each subreach; the length of each subreach is computed and stored automatically in the arc-attribute table of PATHREACHES. The subreach numbers from SECTIONPOLYS also are assigned automatically to each arc and stored in the attribute table. PATHREACHES was used in determining channel slope.

Channel slope

The third subdivision of FLOWPATH was done to determine channel slope for each of the four subreaches used to analyze traveltimes of float trips. The buffer coverage WATERBUF and a line coverage of digitized topographic contours that cross the river (CONTOURS) were combined into a coverage called CONTOURPOLYS using ARCEDIT. Next, GIS techniques were used to combine CONTOURPOLYS with PATHREACHES to create a line coverage called SLOPELINE (not shown in fig. 9) with a node at each subreach end (boat-access site) and at each topographic-contour crossing.

SLOPELINE was used to determine the channel length and fall (difference in altitude) of each subreach. The arc-attribute table for SLOPELINE contains a separate record for each line segment (arc) between adjacent features (subreach ends and topographic contours) along the river. Distances between nodes, in meters, are computed and stored automatically by the software. A software-generated report was created to summarize the information needed to calculate channel slope, including subreach lengths, which were converted from meters to feet. The altitudes at the nodes representing subreaches were interpolated by prorating contour interval by the distance between the contours on each side of a node. The channel characteristics for subreaches 2-5 are listed in table 5.

Table 5.--Channel length, fall, and slope derived using geographic information system (GIS) techniques

Sub-reach number (fig. 3)	Description	Channel characteristics: Length[1] (feet)	Fall (feet)	Slope (foot per foot)
2	Pacific Creek to Triangle-X	49,650	80	0.00161
3	Triangle-X to Deadmans Bar	9,920	23	.00232
4	Deadmans Bar to Lower Schwabacher	29,910	89	.00298
5	Lower Schwabacher to Moose	23,330	84	.00360

[1]Rounded to nearest 10 feet.

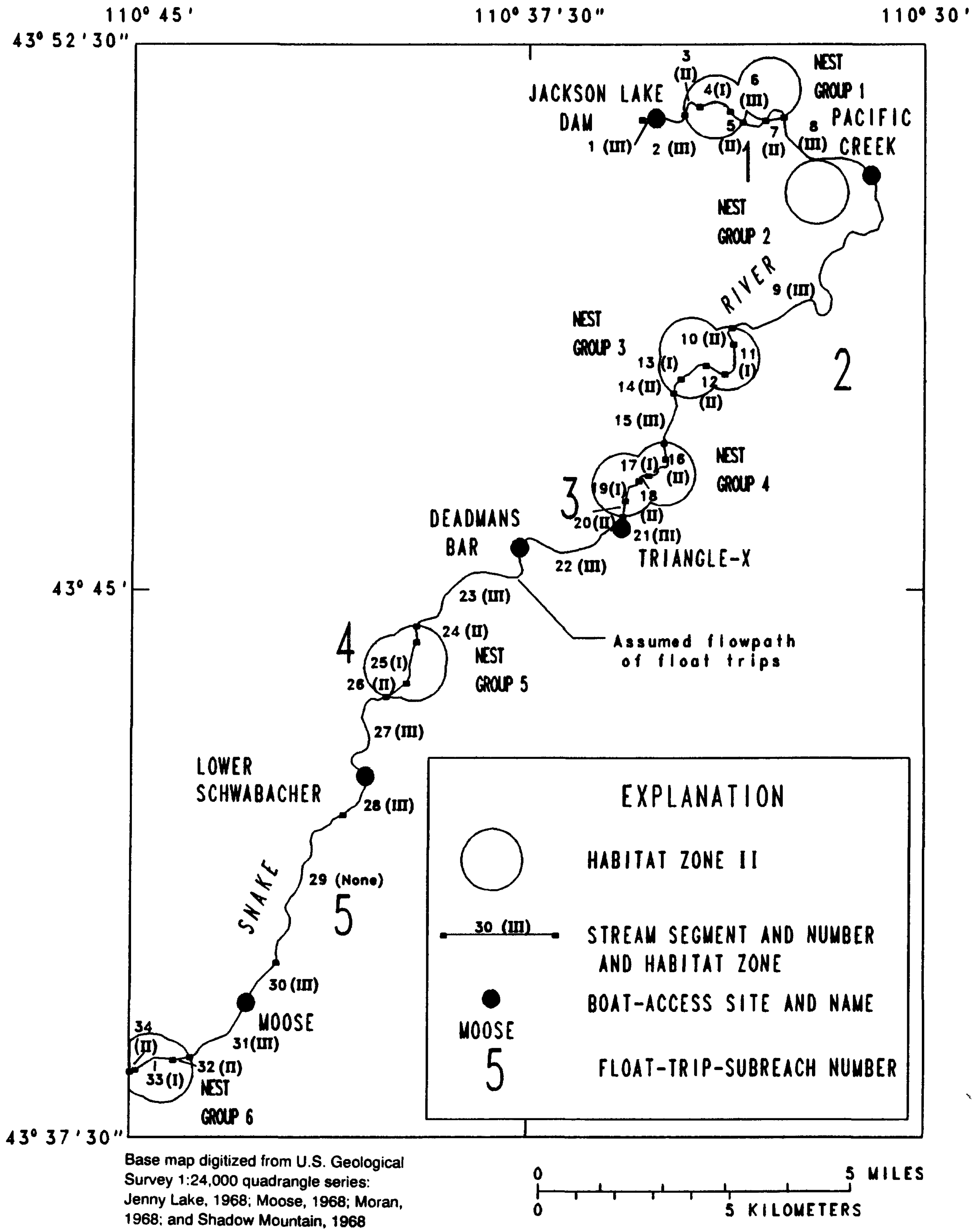
Combination of Habitat Zones and Subreaches

The final step in the GIS analysis was to place nodes representing the subreach ends (boat-access sites) along PATHZONES, in order to determine the incremental distances between each boat-access site and each habitat zone downstream from that site. PATHZONES and SECTIONPOLYS were combined to produce ZONEREACHES (fig. 9), the final GIS coverage for this investigation. A plot of the line representing the Snake River with nodes at habitat-zone boundaries and boat-access sites is shown in figure 10, which was created from ZONEREACHES. A software-generated report was created to retrieve the lengths of stream segments from the feature-attribute table of ZONEREACHES; the information is listed in table 6. The individual stream segments are shown in figure 10. This information was used in estimating traveltimes along segments.

Creation of Maps

GIS techniques were used to produce 6 of the 10 illustrations in this report. ARCPLOT, the graphics subsystem of ARC/INFO, was used to create the maps in figures 1, 3, 8, and 10 and the diagram in figure 9, which is a combination of maps. The components of figure 1 were digitized from maps of various scales. The other maps were created directly from the 1:24,000-scale coverages previously described. The block diagram in figure 2 also is a GIS product.

Figures 3, 8, and 10 demonstrate the potentially powerful reselection capability available with the GIS software. Coverage features can be reselected based on attributes for analysis or display. For example, only perennial streams and water bodies with a surface area greater than 0.2 mi^2 are shown in figure 3. Only the Snake River is shown in figure 8. Symbols in figure 10 were reselected from a point coverage created from the nodes of PATHREACHES using GIS techniques.



Base map digitized from U.S. Geological Survey 1:24,000 quadrangle series: Jenny Lake, 1968; Moose, 1968; Moran, 1968; and Shadow Mountain, 1968
Polyconic projection

Figure 10.--Assumed flowpath of float trips and stream segments in habitat zones, derived using geographic information system (GIS) techniques.

Table 6.--Length of stream segments within habitat zones between boat-access sites, derived using geographic information system (GIS) techniques

Boat-access site	Subreach number (fig. 10)	Segment number (fig. 10)	Habitat zone	Segment length (miles)	Subreach length (miles)
Pacific Creek					
	2	9	III	4.76	
	2	10	II	.31	
	2	11	I	.57	
	2	12	II	.33	
	2	13	I	.48	
	2	14	II	.26	
	2	15	III	.83	
	2	16	II	.25	
	2	17	I	.51	
	2	18	II	.19	
	2	19	I	.43	
	2	20	II	.25	
	2	21	III	.23	9.40
Triangle-X					
	3	22	III	1.88	1.88
Deadmans Bar					
	4	23	III	2.55	
	4	24	II	.25	
	4	25	I	.68	
	4	26	II	.39	
	4	27	III	1.80	5.67
Lower Schwabacher					
	5	28	III	.76	
	5	29	none	2.86	
	5	30	III	.80	4.42
Moose					
Total					21.37

Because GIS is a new analytical tool for water-resources investigations, a schematic diagram (fig. 9) was created, initially as a standard flowchart, to show the steps in the analysis. The boxes of the flowchart were replaced with isometric transformations of the coverages by applying GIS techniques provided by K.J. Hitt (U.S. Geological Survey, oral commun., 1990). Finally, a more realistic representation was obtained with the software-generated perspective transformations shown in figure 9. A perspective view with two vanishing points on a horizon line was drawn on paper, the corners digitized, and an empty coverage generated from the tics. The original coverages then were transformed to fit the perspective view. The effect is that of viewing upstream along the Snake River toward Jackson Lake.

Hypothetical Examples

The channel lengths and slopes (tables 5 and 6) determined using GIS techniques were used with equation 3 to estimate traveltimes of boats (float trips) between specified sites for specified stream discharges. The daily accumulation of time during which boats are present in each habitat zone might be an indication of the potential disturbance of the eagles. Estimations of traveltimes can be made for any number of boats entering the river at any designated fixed or variable interval of time. The following general procedure was used:

1. Designate 0800 hours as time 0, the basis for accumulating times that boats are within each habitat zone.

2. Estimate (using eq. 3) the incremental traveltime of each boat through each stream segment in a habitat zone (table 6 and fig. 10) for a specified float trip between specified boat-access sites and for a specified stream discharge. Channel slopes for traveltime calculations are listed in table 5, and lengths of stream segments are listed in table 6.

3. Compute the elapsed traveltime of each boat from time 0 to upstream and downstream boundaries of each habitat zone.

4. Determine the time intervals (referenced to time 0) during which one or more boats were in each habitat zone. For purposes of estimating potential disturbance of habitat, one or more boats in a given zone at a given time counts the same as one boat.

5. Tabulate the cumulative daily time one or more boats were within each habitat zone and express that time as a percentage of the 12-hour period during which boats launched between 0800 and 1800 hours are on the river (0800 to 2000 hours).

For purposes of illustration, the cumulative daily traveltimes of boats passing through habitat zones I and II for nest groups 3-5 (fig. 8) were estimated for each of four hypothetical example combinations of boats per day and stream discharge:

Example	Period	Boats per day (average)	Discharge (cubic feet per second)
1	Last half of June	102	7,000
2	Last half of July	127	12,000
3	First half of August	152	4,000
4	First half of September	57	2,500

For each example, the semimonthly number of concessionaire boats (fig. 4) was doubled to account for the number of private boats, then divided by the number of days in one-half month (15 or 16) to obtain the average number of boats per day. This was done for each of the seven float trips listed in table 1; trips through subreach 1, however, were excluded from further analysis. The average number of boats per day was distributed into five 2-hour launch periods using the ratios previously described in the section on Float Trips on the Snake River. The average time interval between boats during each 2-hour period was used, although user-defined variable intervals can be applied, if necessary. The all-day float trips (Pacific Creek to Moose, subreaches 2-5) were assumed to start during the first time period, 0800-1000 hours. In these examples, all float trips were completed by 2000 hours. The data used for the hypothetical examples are summarized in table 7, and the results are summarized in table 8.

The results of the hypothetical examples (table 8) indicate how the number of boats per day and the stream discharge affect the percentage of time one or more boats are within the habitat zones. In examples 1 and 2 there are almost identical percentages for each habitat zone, in spite of the large differences in the number of boats per day and in discharge. Boat velocities ranged from 5.16 to 6.13 ft/s in example 1 and from 5.97 to 7.09 ft/s in example 2; the effects of the larger number of boats in example 2 were offset by the effects of larger velocities and shorter traveltimes through the habitat zones. In example 3, the number of boats was even larger, and with the smaller velocities (4.43 to 5.27 ft/s) and longer traveltimes associated with a much smaller discharge, boats were within each zone for a greater percentage of time than in the other three examples. In all four examples, the largest percentage of time during which boats were within the habitat zones occurred at nest group 5 in subreach 4 (figs. 8 and 10); more than one-half of all float trips traverse that subreach (table 1).

Results of using the techniques described in this report could be improved by using daily boat counts instead of semimonthly averages and by applying a more realistic distribution of starting times of the float trips. The use of equal time intervals between boats within each 2-hour period maximizes the percentage of time one or more boats are within the habitat zones because it minimizes the occurrence of more than one boat at a time in a zone. Any variation in the time between boats will result in percentages equal to or smaller than those listed in table 8. In the absence of representative field observations, queueing-theory techniques might be used; for example, the Poisson distribution, commonly used to simulate the development of waiting lines, might be used to simulate starting times of float trips.

CONCLUSIONS

For this investigation, traveltimes estimated from published equations are representative of actual traveltimes, on the basis of comparison with limited data collected by the National Park Service River Patrol. The use of mean monthly discharge of the two major tributaries to adjust the instantaneous discharge in the Snake River produced acceptable estimates of traveltimes in the river. Provided a realistic time distribution of boats is used, the techniques can be used to evaluate the passage of large numbers of free-floating boats through designated areas of interest, such as wildlife-habitat zones, along other rivers.

Table 7.--Float-trip data used for hypothetical examples of estimated traveltimes of boats passing through habitat zones I and II

Float trip (sub-reach number)	Total[1]	Average per day	Number of boats, rounded to whole numbers — Distribution of daily average by launch time period: 0800-1000	1000-1200	1200-1400	1400-1600	1600-1800
			Example 1--Last half of June				
1	0	0	0	0	0	0	0
2	56	4	1	1	1	1	0
2-3	324	22	3	5	6	5	3
2-5	60	4	[2]4	0	0	0	0
3-5	16	1	0	0	1	0	0
4-5	816	54	8	13	14	12	7
5	260	17	3	4	4	4	2
	1,532	102					
			Example 2--Last half of July				
1	30	2	0	1	1	0	0
2	74	5	1	1	1	1	1
2-3	412	26	4	6	7	6	3
2-5	74	5	[2]5	0	0	0	0
3-5	18	1	0	0	1	0	0
4-5	1,078	67	10	16	17	15	9
5	338	21	3	5	5	5	3
	2,024	127					
			Example 3--First half of August				
1	6	1	0	0	1	0	0
2	64	4	1	1	1	1	0
2-3	480	32	5	8	8	7	4
2-5	70	5	[2]5	0	0	0	0
3-5	16	1	0	0	1	0	0
4-5	1,232	82	12	19	21	18	12
5	412	27	4	6	7	6	4
	2,280	152					
			Example 4--First half of September				
1	32	2	0	1	1	0	0
2	24	2	0	1	1	0	0
2-3	224	15	2	4	4	3	2
2-5	16	1	[2]1	0	0	0	0
3-5	2	0	0	0	0	0	0
4-5	546	36	5	9	9	8	5
5	14	1	0	0	1	0	0
	858	57					

[1]Number of concessionaire float trips (fig. 4), doubled.
[2]All-day float trips assumed to start during the earliest time period.

Table 8.--Estimated cumulative daily percentage of time one or more boats are within habitat zones I and II, for four hypothetical examples

[Number in parentheses indicates average number of boats per day passing through habitat zones in indicated river subreach]

Sub-reach number	Segment number (fig. 10)	Nest group number	Hab-itat zone	Percentage of time between 0800 and 2000 hours that one or more boats are within specified habitat zone for indicated example: Example number 1	2	3	4
2	10	3	II	22 (30)	24 (36)	34 (41)	18 (18)
2	11	3	I	40	42	64	32
2	12	3	II	22	24	38	18
2	13	3	I	35	36	55	27
2	14	3	II	18	18	31	15
2	16	4	II	18 (30)	18 (36)	27 (41)	14 (18)
2	17	4	I	35	39	58	28
2	18	4	II	12	15	20	10
2	19	4	I	30	33	48	24
2	20	4	II	18	18	27	14
4	24	5	II	28 (59)	29 (73)	49 (88)	24 (37)
4	25	5	I	70	72	85	63
4	26	5	II	50	46	73	36

Applications of geographic information system (GIS) techniques in this investigation were limited, considering the potential analytical power available with GIS. GIS techniques accurately translated dimensionally defined habitat zones into map features for further analysis. The GIS also provided the physical dimensions (reach lengths and channel slopes) needed for estimating traveltimes of boats between boat-access sites and between successive intersections of the Snake River with areas of eagle habitat.

Map features and feature attributes can be added to the GIS, changed, or deleted easily, and updated analyses readily generated. For example, nest locations or habitat-zone dimensions can be changed and new lengths of stream segments quickly determined. Also, new coverages can be added as needed, and increasingly complex analyses performed. GIS graphics can be used to produce a variety of displays of information derived from the stored data, such as maps of selected combinations of both input and GIS-generated features, or diagrams illustrating the steps used in the GIS analysis.

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