FLOODPLAIN ANALYSIS FOR THE GARCIA TRADING POST AREA
CANYON DE CHELLY NATIONAL MONUMENT
CHINLE, ARIZONA

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

This report presents the results of a study that quantified flood flows and associated hydraulic characteristics for the 100- and 500-year and worst case floodplains for Chinle Wash at the Garcia Trading Post near Canyon de Chelly National Monument (CACH). Additionally, the effectiveness and possible impacts of a levee, one alternative to protect the site from flooding, were analyzed. The study was conducted by the Water Resources Division to provide Southwest Region planners with information necessary for development planning and to permit compliance with the National Park Service's Floodplain Guidelines.

The study consisted of estimation of flood magnitudes, survey of channel and floodplain geometry, determination of hydraulic roughness, and computer simulation of flood flows through the area. The 100- and 500-year flood peaks were estimated using regional regression equations developed by the U.S. Geological Survey. The worst case flood peak was extracted from a previous study by the U.S. Army Corps of Engineers (COE). The COE backwater computer model, HEC-2, was then used to predict water-surface elevations and expected depths and velocities for the floods of interest. Water surface elevations were superimposed on a topographic map and depicted on channel profiles to show the extent of inundation in the study area and the flood depths relative to the floor elevations of key structures at the site.

The results of the study reveal that all structures on the Garcia Trading Post site are within the 100- (base floodplain) and 500-(critical floodplain) year floodplains. The main floors of buildings 5, 11, and 12, as referenced from a Southwest Region planning map, and the lower floor of the Garcia Trading Post would be inundated by about 1 to 2.5 feet of water during a 100-year flood event. The upper floor of the Garcia Trading Post would be 2 to 3 feet above the expected 100-year flood level. A 500-year flood event would inundate all floors of all structures with flood depths ranging from 1 to 5 feet. The combination of flood depth and velocity during a 100-year flood may topple able-bodied adults that may be trapped in the flood.

The Garcia Trading Post site could be protected from the 100- and 500-year floods by a levee that could be constructed on the south overbank of Chinle Wash. However, such a structure would increase flow velocities through Chinle Wash by about 70 percent during the 100- and 500-year flood events. Increased velocities may alter the existing sediment transport characteristics through Chinle Wash, which in turn could increase the risk of failure of a levee if not properly designed. A levee may also exacerbate flood situations at the Thunderbird Lodge and the CACH campground.

Construction activities at the site may adversely impact wetlands. Consultation with the U.S. Fish and Wildlife Service or the COE is recommended to determine if mitigation is required.

INTRODUCTION

BACKGROUND

The Garcia Trading Post site is located approximately 0.5 miles west of the existing Canyon de Chelly National Monument (CACH) visitors center/headquarters. The Joint Management Plan for Canyon de Chelly proposes that the Navajo Tribe and the National Park Service (NPS) jointly develop the Garcia Trading Post site by renovating the existing abandoned structures on the property and constructing new facilities. Potential developments are a visitors' orientation center, NPS and Tribal offices, a vendor village, food services, and picnicking facilities. The proposal would provide relief from the crowded office and visitor facilities at CACH headquarters (NPS, 1989)

NPS Southwest Region planners suspected early in the planning process that portions of the site could be within the 100-year floodplain of Chinle Wash and that actions may be required for compliance with the NPS floodplain guidelines. The Water Resources Division (WRD), after a request from Regional staff, performed a preliminary evaluation of the flood hazard in August 1989. Based on the field investigations and a review of existing reports, the WRD concluded that the entire site was most likely within the 100-year floodplain and recommended further study to determine flood depths and velocities at the site. Upon the request of the Southwest Region, WRD initiated a more detailed flood investigation in November 1989 and completed the preliminary modeling efforts in December 1989. This report presents the results of the flood study and addresses issues associated with the 100- and 500-year and worst case floods.

OBJECTIVES

For Chinle Wash in the immediate area of Garcia Trading Post:

1. determine water surface elevations and velocities for the 100- and 500-year and Probable Maximum Flood (PMF) events;

2. determine water surface elevations and velocities for floods caused by the failure of Tsaile Dam; and

3. assess structural alternatives for flood protection.

Upon consideration of the situation at Garcia Trading Post, it was decided to combine the evaluations of the PMF and Tsaile Dam failure into a single, worst case flood event. This decision was made because a classic PMF evaluation is intended to represent the greatest flood possible. The presence of upstream dams, however, result in a possibility for a flood of greater magnitude than a naturally occurring PMF. The flood magnitude used in this evaluation is an estimate of the flow which would occur if the Tsaile Dam failed during a PMF.

LOCATION AND ENVIRONS

WATERSHED DESCRIPTION

The headwaters of Chinle Wash, including Tsaile, Wheatfields, Whiskey, and Coyote Creeks, originate in the highlands of the Chuska Mountains (Figure 1). Two reservoirs, Tsaile Dam and Wheatfields Dam, are located in the foothills of the Chuska Mountains and serve to regulate flows through the Monument. Flowing westward from the reservoirs, the headwater tributaries collect water from the Defiance Plateau area and funnel it through two steep-walled meandering sandstone canyons--Canyon del Muerto and the Monument's namesake Canyon de Chelly. The confluence of the canyons, about 3 miles to the east of CACH headquarters, forms the mainstem of Chinle Wash, which carries water past headquarters and the Garcia Trading Post area.

The watershed area above the trading post is about 650 square miles. Elevations vary from about 9,800 feet Mean Sea Level (MSL) in the Chuska Mountains, to about 5,600 feet at CACH headquarters. Average annual precipitation varies from 16 to 20 inches per year in the highlands to about 9 to 12 inches per year at the Monument headquarters. August is the wettest month of the year, averaging about 1.7 inches of precipitation at the Monument headquarters primarily from late summer thunderstorms (NPS, 1986). Not surprisingly, peak flows in the watersheds around CACH commonly occur in late July through early September (Roeske, 1978).

Chinle Wash, as it exits the mouth of the canyon near headquarters, is a broad sand channel bordered by narrow floodplains vegetated with tamarisk and cottonwoods. Due to sedimentation, the south bank of Chinle Wash in this area is virtually non-existent. In fact, the sand channel in places is higher in elevation than its adjoining floodplain. This phenomenon may cause even small discharges to break out of the channel.

GARCIA TRADING POST

The 6.4 acre Garcia Trading Post tract occupies the geomorphic floodplain of Chinle Wash and is located in riparian vegetation between the Wash and Highway 7 (Figure 2). Key structures on the site, referenced by number on Figure 3, include the former Garcia's Trading Post (building #10), the trader's residence (building #5), a former retail store (building #11), residence (building #12), and several smaller out buildings and structures associated with the above major facilities.

The Garcia Trading Post has been constructed so that the floor of the eastern one-half of the structure is about four feet lower than the floor of the western one-half of the structure. For the purposes of this report, the eastern floor is referred to as the lower floor, and the western floor is referred to as the upper floor.

PREVIOUS INVESTIGATIONS

Previous floodplain mapping efforts and investigations for Chinle Wash near the Garcia Trading Post, the town of Chinle, and CACH headquarters have been conducted by Morrison Maierle, Inc., and the U.S. Army Corps of Engineers (COE). A review of

FIGURE 1

Vicinity Map for Canyon de Chelly National Monument, Chinle Wash Watershed and the Garcia Trading Post

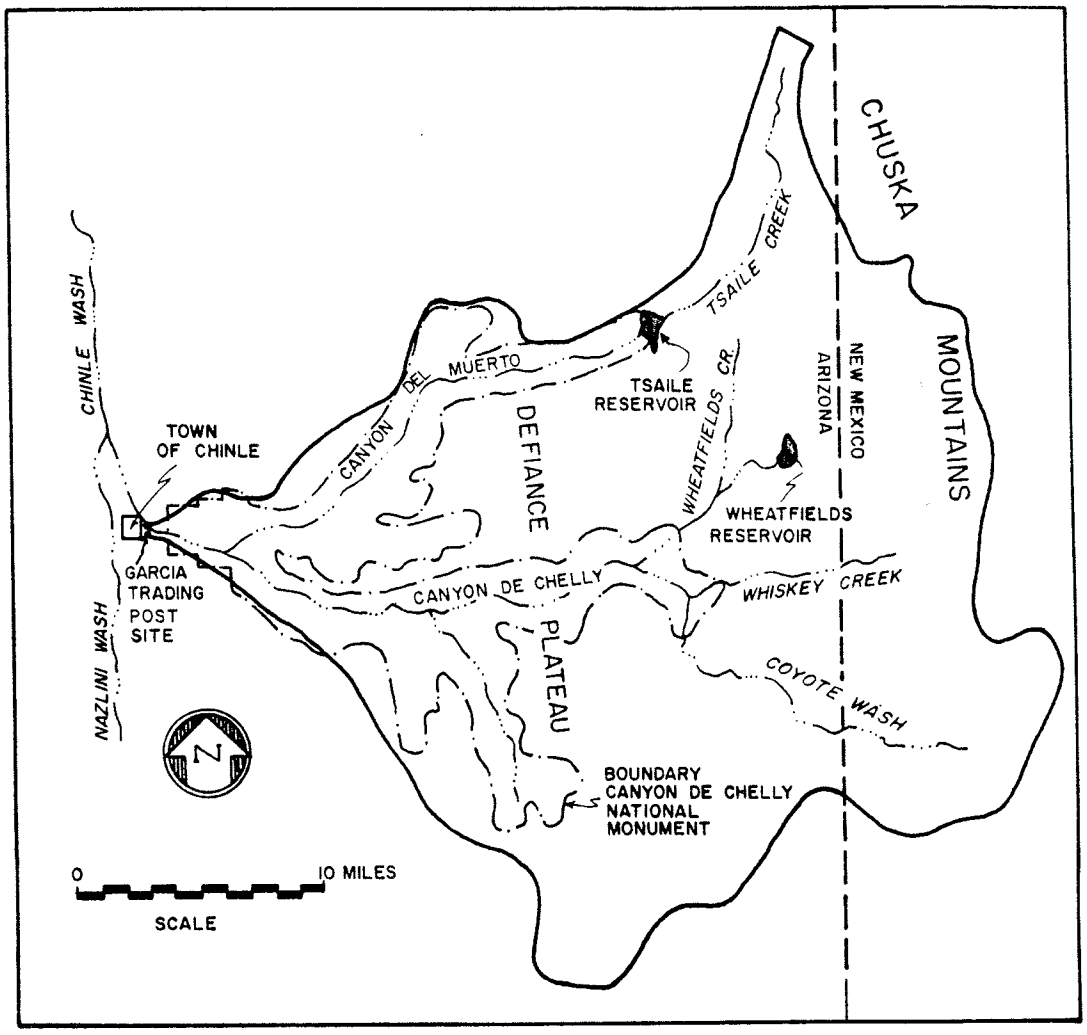

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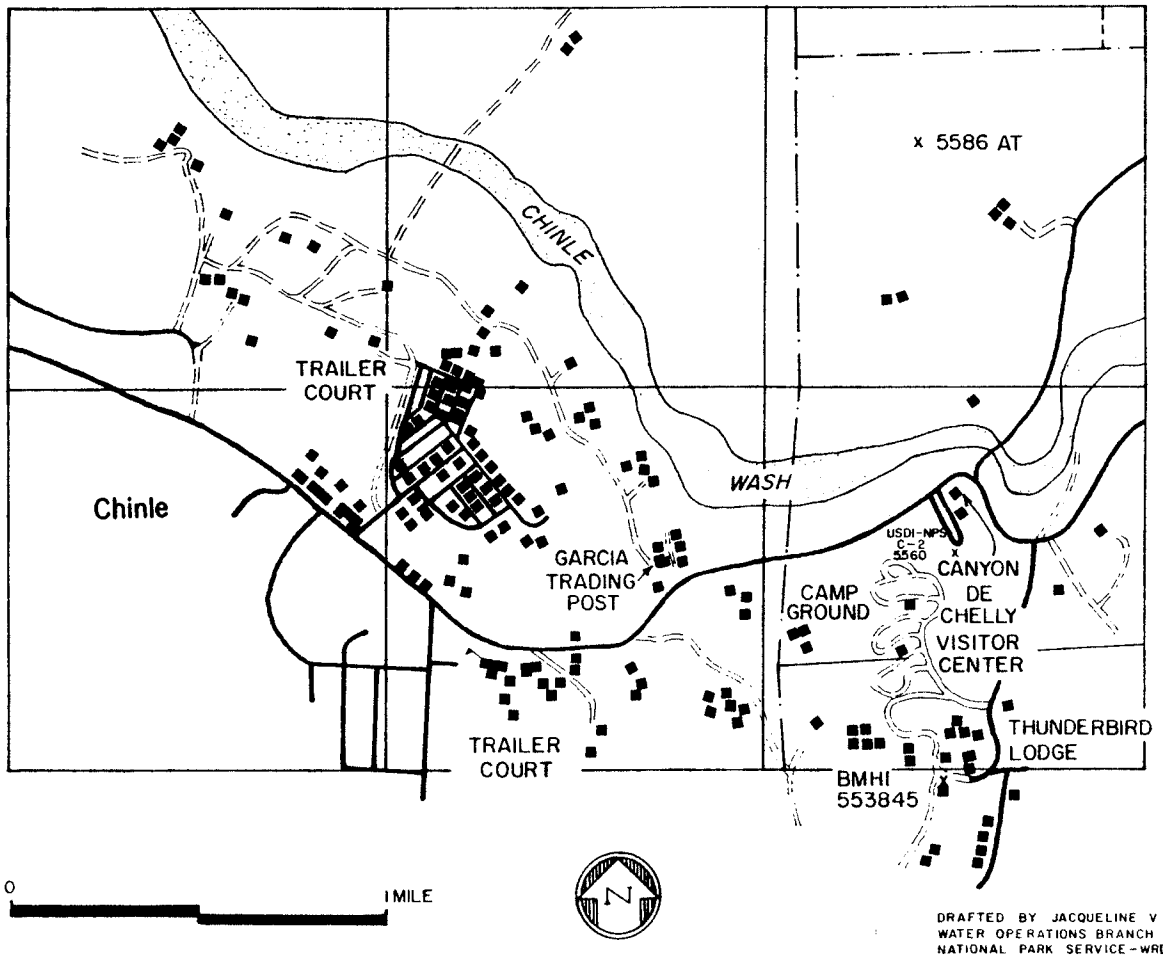
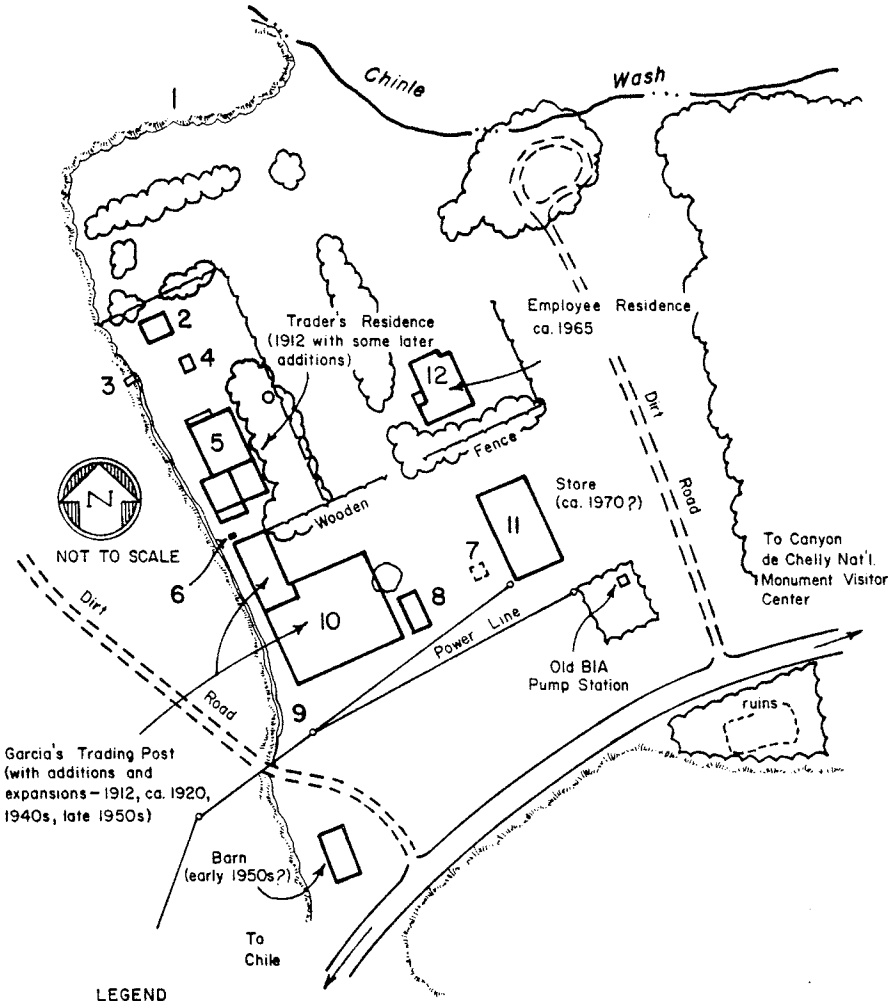
FIGURE 2

Garcia Trading Post Floodplain Study Area





LEGEND

1. Sheep/horse corral
2. Employee House (1920 chicken coop converted to housing – poor condition)
3. Dugout (1920 food storage converted to chicken coop)
4. Restroom (1950s)
5. Trader's Residence
6. Barbecue Pit
7. Site of stone hut
8. Gas pump canopy
9. Retaining wall
10. Garcia Trading Post
11. Store
12. Store Residence

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GARCIA TRADING POST SITE

FIGURE 3

these studies provides an overview of the type and magnitude of flooding caused by Chinle Wash and other drainages in the vicinity of Chinle, Arizona. A report issued by Morrison Maierle, Inc. in 1977 contains a flood-hazard map that depicts the Garcia Trading Post area as being within the "approximate boundaries" of the 100-year floodplain. The type of floodplain mapping in this report is equivalent to the preliminary flood hazard maps prepared by the Federal Insurance Administration of the Department of Housing and Urban Development. Specific information about flood depths and velocities were not determined by Morrison Maierle. However, they note that flash-flooding caused by short-duration thunderstorms occur throughout the Navajo Nation.

Three investigations by COE, including two reports and a floodplain map, contain additional flood information for this area. In 1981, COE delineated the 100- and 500-year floodplains for the area around CACH headquarters, the Thunderbird Lodge, and the CACH campground facilities. The Thunderbird Lodge and the campground are located on a historic channel of Chinle Wash. Maximum Flood depths relative to ground elevation in this area are estimated to be 4 and 6 feet for the 100- and 500-year floods, respectively.

In a 1985 report prepared for the NPS, COE analyzed the extent of flooding in the event of the failure of Tsaile Dam. Two scenarios were analyzed, including flooding due to a normal reservoir depth failure and a worst feasible failure mode. COE predicts that both of these events would inundate to varying degrees the Thunderbird Lodge Area, the campground area, concession employees housing area, and the NPS utility area.

In a 1988 reconnaissance report prepared for the Navajo Tribe, COE analyzed potential flooding and flood protection alternatives for the town of Chinle (about one-half mile downstream of the Garcia Trading Post). Many structures in Chinle were shown to be vulnerable to the 100-year flood. A devastating flood in the Chinle area is also described in this report. In 1964, a flash flood that originated in Nazlini Wash destroyed a bridge and resulted in the death of seven people. Nazlini Wash, which has headwaters in the Defiance Plateau, confluences with Chinle Wash about 3 miles below the Garcia Trading Post.

METHODS

FLOOD PEAK ESTIMATION

Discharge estimates for the 100- and 500-year floods in Chinle Wash were determined by utilizing regression equations developed by the U.S Geological Survey (USGS) in *Methods for Estimating the Magnitude and Frequencies of Floods in Arizona* (Roeske, 1978). The calculated values were then compared with flood peaks computed for previous flood investigations by the COE. Values calculated by WRD are similar to those used by the COE for their 1981 investigation at the CACH headquarters and Thunderbird Lodge area. The COE study also utilized the USGS regression equations in estimating their flood peaks. WRD considered the flood peak estimates by COE to be reasonable for the watershed characteristics displayed in the contributing watersheds of Chinle Wash. Thus, to provide consistency for future floodplain mapping efforts in the combined area of the CACH headquarters and the Garcia Trading Post, the 1981 COE 100- and 500-year flood-peak estimates were selected for this study.

The worst case flood peak estimate selected for this study represents the worst feasible failure mode for Tsaile Dam as determined by the COE in their 1985 study *Potential Flooding From the Failure of Tsaile Dam*. COE calculated a theoretical flood peak at the mouth of Canyon de Chelly based on the scenario of the failure of Tsaile Dam due to the inflow of a PMF.

The 100- and 500-year, and the worst case flood peaks selected for this study are:

Q100 = 27,000 cfs Q500 = 58,000 cfs Worst Case = 110,000 cfs

Where: Q100 = the peak 100-year discharge
Q500 = the peak 500-year discharge and
Worst Case = the peak discharge due to breaching of Tsaile Dam by the Probable Maximum Flood.

The 100- and 500-year floods, by definition, have a 1.0 and 0.2 percent chance, respectively, of being equaled or exceeded in any single year. On the other hand, no probability can be attached to flood-flow estimates which are based solely, or partially, on the PMF event.

FLOOD MODELING

A backwater-simulation computer model developed by the COE, HEC-2 (COE, 1982), was employed to predict water surface elevations and velocities for the selected flood flows, and to evaluate the effect on flood-flows from a hypothetical levee on the south overbank of Chinle Wash. Necessary model information, including land surface topography and hydraulic roughness (resistance to flow) in the floodplain, were collected during a field survey by WRD staff. The reach selected for study extends about 2,000 feet; from just downstream of the end of the water well access road in the channel up to the approximate location of the downstream extent of the 1981 COE study. Critical portions of the study reach were identified and six cross section profiles were surveyed (see Table 1 for a brief description of the cross section locations). The cross sections all run perpendicular to the channel and are numbered sequentially from downstream (cross section 1) to upstream (cross section 6). Special measurements of the topography near the trading post buildings were collected to accurately predict water surface elevations in the development.

Topography was surveyed using a Lietz SET4 total station which includes an EDM, theodolite, and electronic data logger. Survey control was established using USDI-NPS Brass Cap C-2, located just south of the visitor center parking lot. The brass cap was assigned coordinates (Northing, Easting, and Elevation) of 0 feet north, 10,000 feet east, and 100 feet elevation. Control points were established in visible, stable locations on both sides of the channel and surveyed-in relative to the brass cap. Cross section and topography points were surveyed later relative to the grid defined by the control points. All surveyed elevations were converted to MSL in the office.

Hydraulic roughness (Manning's "n") values were estimated for each cross section from experience and reference to a USGS publication (Barnes, 1977). Values ranged from a low of 0.035 in the sand bed channel to a high of 0.070 for rough overbank areas. Three of the six cross sections for the study reach were placed through the area proposed for

development. Cross section 4 extended from a point high on the north bank to the road immediately south of the trading post building. Cross section 5 was located adjacent to the pump house on the south overbank, east of the trading post.

TABLE 1

Cross Section Description
All Cross Sections run perpendicular to the Channel

Cross Section Number	Location Description
1	About 1,200 feet downstream of the Garcia Trading post site. Located at the northern end of the dike that protects pumping facilities.
2	About 600 feet downstream of the Garcia Trading Post site.
3	Connects with the northern boundary of the Garcia Trading Post tract. Bisects the angle that is formed by Chinle Wash where its thalweg changes from a westerly to a northerly flow path.
4	In the Garcia Trading post developments. The section begins on the south side of Highway 7, then runs through buildings 10 and 12, and then perpendicular across Chinle Wash to a point high on the north bank.
5	About 600 feet upstream of the Garcia Trading Post Site. Located adjacent to the abandoned BIA pump station.
6	About 1,300 feet upstream of the Garcia Trading Post site. Located near the western boundary of the area mapped by the Army Corps of Engineers in 1981.

Cross section 6 extended across the floodplain near the upper end of the area proposed for development.

All field information was checked for errors and reduced into HEC-2 format. Various runs of the model allowed adjustment of the input conditions, such as the selected roughness values and a determination of the sensitivity of critical variables. No adjustment to the input data was found to be necessary.

An assumption of subcritical flow in Chinle Wash was made which means that hydraulic effects are experienced upstream of channel features, such as constrictions and changes in roughness. This assumption is fairly certain given the roughness and gradient of the channel in this reach. To initiate HEC-2 for a subcritical case, it is

necessary to specify starting conditions at the downstream-most cross section. For this study, the flow at cross section 1 was assumed to be at normal depth. Normal depth is the depth of flow that is attained in conditions of subcritical flow, free from the effects of backwater. The channel conditions at this location are such that normal depth is very likely to occur as there are no channel features in the area that would cause the flow to be at critical depth or subject to backwater.

The alternative of flood mitigation by placement of a levee along the south bank was investigated using the floodway encroachment option in HEC-2. This option allows evaluation of the levee elevation required for protection from a specific flood. Also, hydraulic conditions in the channel that result from the constricted flow area can be estimated. In this study a hypothetical levee was placed in the model at the location of the south bank for cross sections 4 through 6. It should be noted that design criteria for the levee other than elevation cannot be evaluated in this manner.

RESULTS

Modeling results for the existing floodplain without mitigation, as well as for a hypothetical levee, are presented in this section. The results for both cases are described in detail only for cross sections 4 and 5. Cross sections 1 through 3 are located outside the proposed area of development, thus flooding in these cross sections is not discussed. Cross section 6 is within the area proposed for development but is outside of the immediate Garcia Trading Post area. However, the estimated flood depths and velocities for these cross sections are presented in tabular form in Table 2.

FLOODPLAIN ANALYSIS--NO MITIGATION

100-Year Flood

The water surface elevations at cross-sections 4 and 5 are predicted to be 5,525.3 and 5,526.2 feet MSL respectively. These elevations have been plotted on a one-foot contour map, and the 100-year floodplain has been delineated and is depicted in Figure 4. The Garcia Trading Post, and building numbers 5, 11, and 12 are within the base floodplain. The estimated depth of flooding in relation to the floors of the major structures is depicted in Figure 5. The main floors of buildings 5, 11, and 12 and the lower floor of building 10 would be inundated by about 1 to 2.5 feet of water during a 100-year flood event. The upper floor of building 10 would be 2 to 3 feet above the expected 100-year flood level.

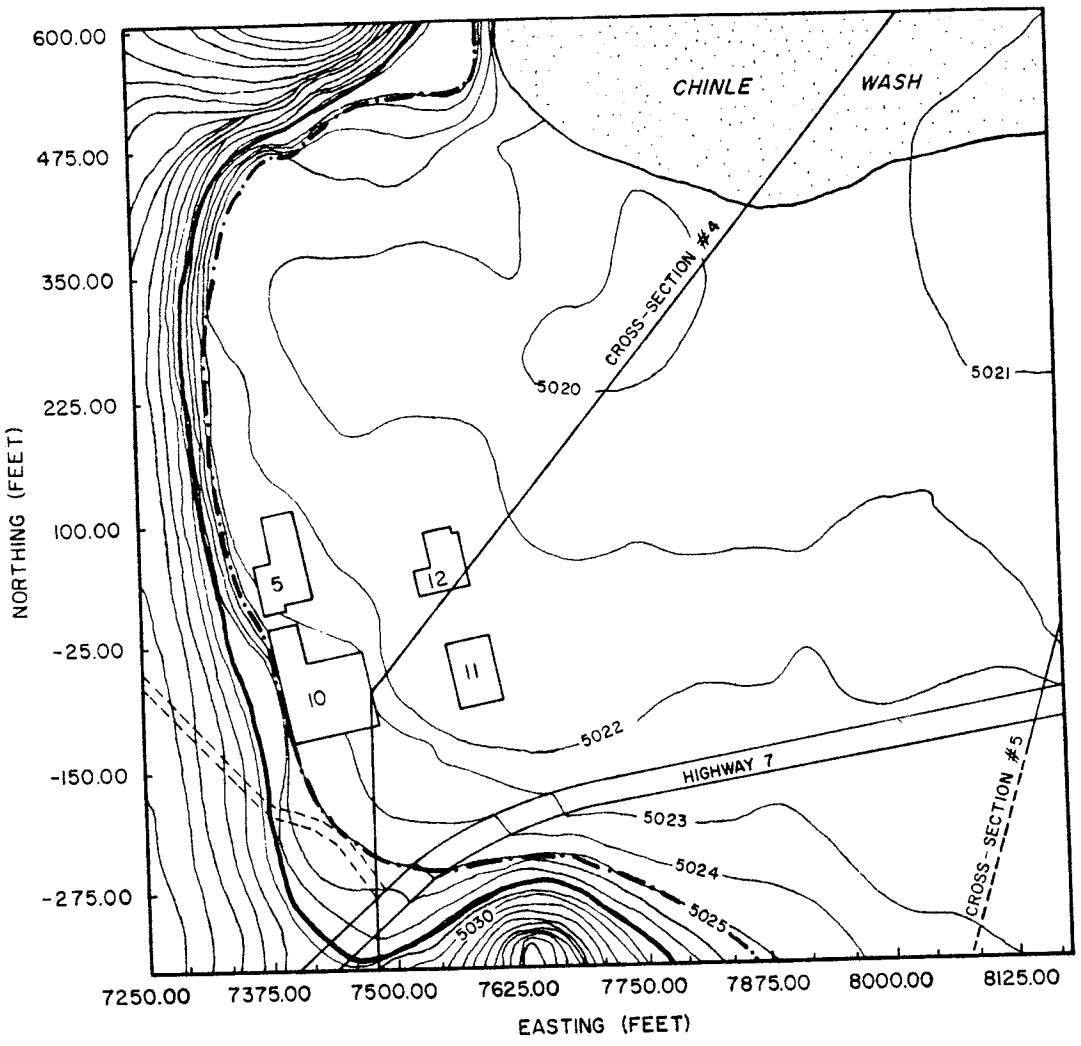
Flow velocities in the area inundated by the base flood in the Garcia Trading Post area are predicted to be in the 2 to 4 feet per second range. The depth of flow above ground level in the area is estimated to be about 3 feet. This combination of velocity and depth may topple able-bodied adult people. Children and people with physical disabilities would most likely be toppled by this flood. (Abt, et al., 1989.)

500-Year Flood

The predicted water surface elevations for cross sections 4 and 5 are 5,528.4 and 5,528.9 respectively. The resulting area of inundation is depicted on Figure 4. Flood

FIGURE 4

100- AND 500-YEAR FLOODPLAINS FOR CHINLE WASH
GARCIA TRADING POST SITE



100-YEAR FLOODPLAIN BOUNDARY
ELEVATION AT CROSS-SECTION #4: 5025.3
" " CROSS-SECTION #5: 5026.2

500-YEAR FLOODPLAIN BOUNDARY
ELEVATION AT CROSS-SECTION # 4: 5028.4
" " CROSS-SECTION # 5: 5028.9

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FIGURE 5

CHINLE WASH FLOOD STUDY
Cross-section 4.000 Depicting Relative Depth
of the 100-year Flood to Floor Elevations

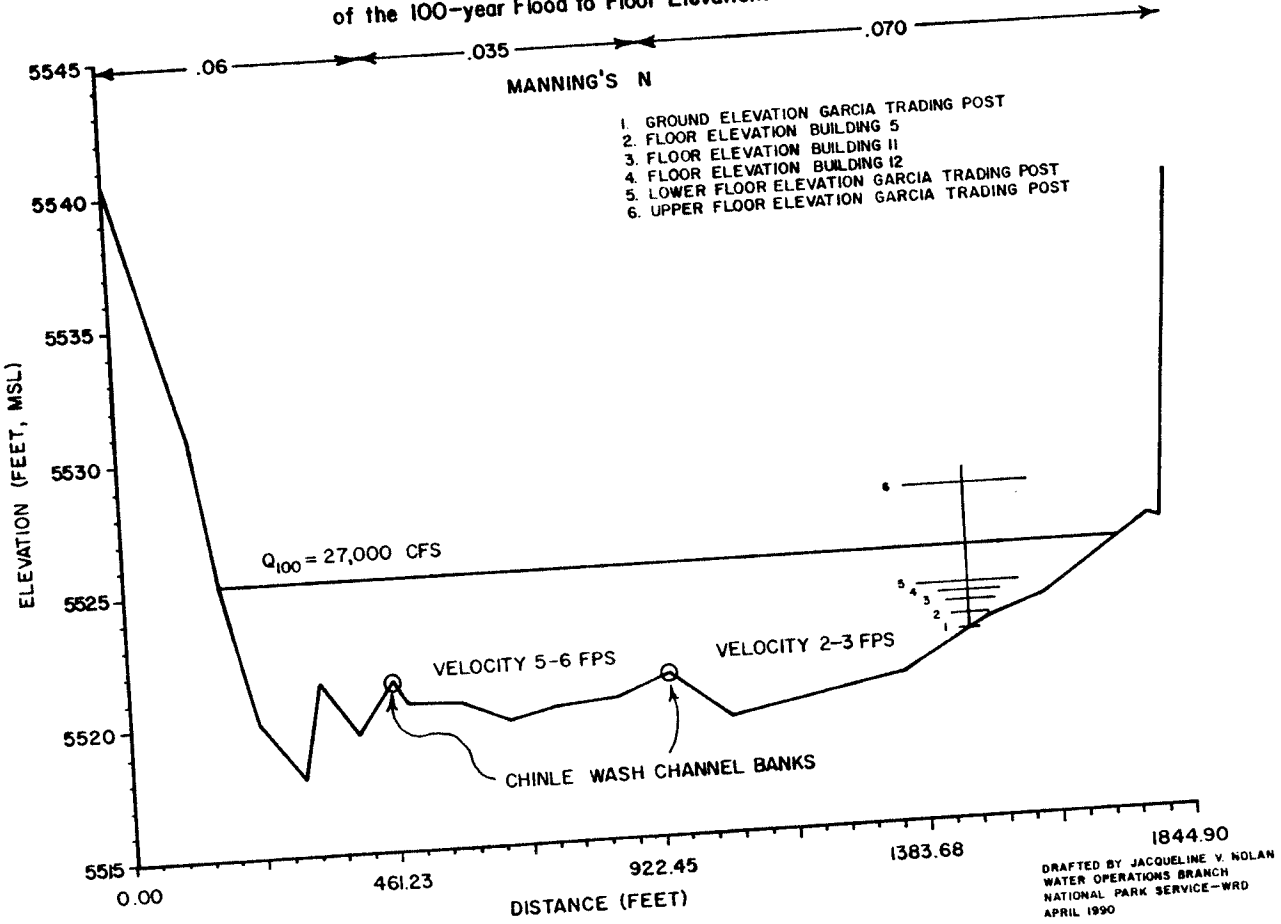
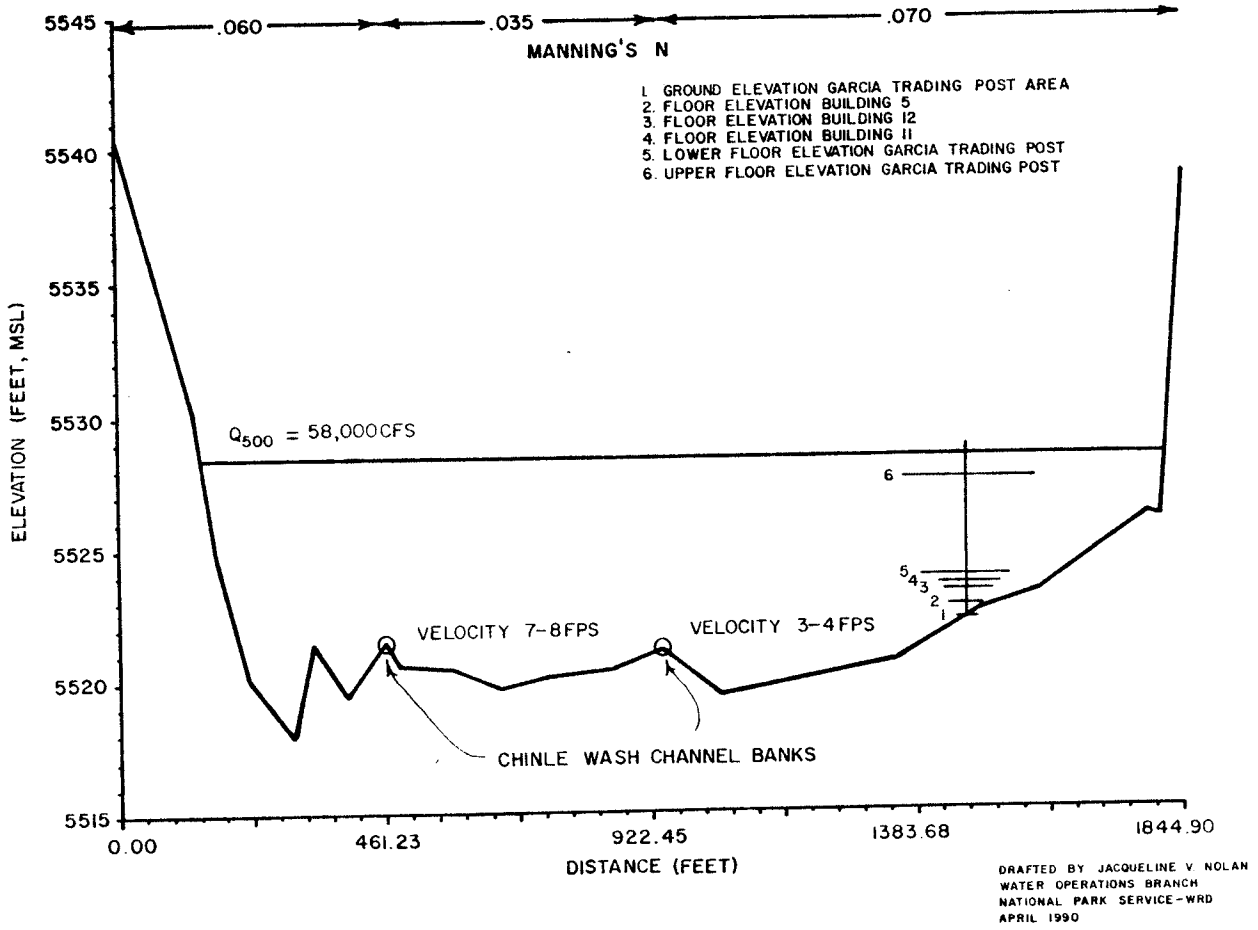


FIGURE 6

CHINLE WASH FLOOD STUDY

Cross-section 4.000 Depicting Relative Depth
of the 500-year Flood to Floor Elevations



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depths relative to the floor elevations of major structures are depicted in Figure 6. The main floors of buildings 5, 11, and 12 and the lower floor of building 10 would be inundated by about 1 to 5 feet of water. The upper floor of building 10 would be inundated by about 1 foot of water.

Flow velocities in the vicinity of the Garcia Trading Post, inundated by the 500-year flood, are predicted to be in the 3 to 6 feet per second range. The depth of flow above ground level is estimated to be about 6 feet. This combination of velocity and depth is considered hazardous to humans. (Abt, et al., 1989.)

Worst Case Flood

The estimated water surface elevations and velocities for this flood on the south overbank at cross sections 4 and 5 are 5,532.4 and 5,532.5, and 5 and 7 feet per second, respectively. This flood is so large that the cross section surveys did not extend high enough to contain the flow. When this happens, HEC-2 extends the end points of the cross section vertically to facilitate computation of water surface elevation. As a result, the estimates of water surface elevation and velocity should not be considered very accurate for this flood. The results are included in Table 2, however, to present a rough estimate of the elevation above which there is essentially no chance for inundation to occur.

FLOODPLAIN ANALYSIS WITH A HYPOTHETICAL LEVEE

Table 3 presents the calculated 100- and 500-year flood elevations based on the assumption that these events are contained within the Chinle Wash channel by a levee that could be constructed on the south overbank. These elevations can be useful in determining the approximate design elevation of a levee if this alternative were selected to protect the Garcia Trading Post site.

HEC-2 model results also indicate that a levee would increase flood-flow velocities through the channel adjacent to the levee as compared to channel velocities that were predicted for floods without mitigation. Table 3 presents a comparison of the predicted 100- and 500-year flood velocities in Chinle Wash, with and without a levee. A levee would increase the flow velocities by as much as 70 percent during the 100- and 500-year flood events. The increased velocities may alter the existing sediment transport regime in Chinle Wash, which in turn has important implications for the design of a protective levee.

DISCUSSION

Some results of this study have implications that could not be technically resolved within the scope of this study, but nevertheless require discussion at least in a hypothetical sense. It is hoped that this discussion will assist in framing objectives for additional hydrologic, engineering, and environmental investigations if planning for the Garcia Trading Post proposal is pursued beyond its present stage.

If a levee such as the one modeled for this study is pursued as a preferred flood-mitigation alternative for the Garcia Trading Post, certain questions concerning design, placement, and construction should be addressed by additional hydrologic studies. The

TABLE 2

Predicted water-surface elevations (WSEL) and velocities (VEL) at the right overbank for surveyed cross sections of Chinle Wash near Garcia's Trading Post

Cross Section Number	Q100 WSEL (Feet MSL)	Q100 VEL (Ft/Sec)	Q500 WSEL (Feet MSL)	Q500 VEL (Ft/Sec)	Worst Case WSEL (Feet MSL)	Worst Case VEL (Ft/Sec)
1	5,520.1	2.4	5,523.0	3.4	5,526.5	4.3
2	5,522.3	2.3	5,525.4	3.1	5,529.5	3.8
3	5,524.1	1.6	5,526.7	2.4	5,530.1	3.6
4	5,525.3	2.7	5,528.4	3.4	5,532.4	4.2
5	5,526.2	4.3	5,528.9	5.8	5,532.5	7.4
6	5,527.9	3.7	5,530.7	5.2	5,534.3	6.8

facilities of the Thunderbird Lodge and the park campground are located within an historic stream channel that is within the 100- and 500-year floodplains of Chinle Wash. At one time, this channel routed water to the east of the existing headquarters area, then southward through the present Thunderbird Lodge Area, and then north through the campground area and back to Chinle Wash. If not properly designed, a levee that would extend from the Garcia Trading Post to the proximity of CACH headquarters could exacerbate a flood situation at the Thunderbird Lodge and the campground area, as well as to the Garcia Trading Post by trapping and retaining flood waters.

Also, additional study of the effect of the increased flood velocities on the elevated sand channel, particularly the sediment transport regime of Chinle Wash is needed. The Chinle Wash floodplain has been encroached upon by man-made structures, the most notable of which are Highway 7 and a dike associated with a ground-water pumping facility north and across Chinle Wash from the Garcia Trading Post. The effect of these structures has been to constrict the stream channel and floodplain development of Chinle Wash. A structure such as a levee which would extend from the Garcia Trading Post to the headquarters area would further constrict the Chinle Wash floodplain. By reducing the cross-sectional area of Chinle Wash, flood velocities may be increased which could initiate down-cutting of the channel adjacent to the levee. Accelerated down-cutting could increase the risk of levee failure by undercutting the bank on which the levee is constructed. This suggests that subterranean toe protection should be a design consideration. In addition, down-cutting would most likely increase the quantity of sediment that would be transported from the Garcia Trading Post area downstream to be redeposited in new areas of the Wash. This relocated sediment load may affect the flood characteristics of Chinle Wash as it flows through the Town of Chinle. A sediment model may assist in determining if down-cutting of the channel is a valid concern.

Finally, portions of the floodplains associated with Chinle Wash, where a levee or other structures may be constructed, are probably wetlands. New construction in this area may adversely impact the wetlands. Additional investigations are required to determine if, in fact, wetlands exist at the site and to determine if mitigation is required.

CONCLUSIONS AND RECOMMENDATIONS

The Garcia Trading Post is in the 100-year floodplain (base floodplain for NPS guidelines) of Chinle Wash. NPS floodplain guidelines require mitigation for actions that will be in the base floodplain. If critical actions (as defined by NPS floodplain guidelines) are to be in the area, the site must be protected against the 500-year event. The main floors of buildings 5, 11, and 12 and the lower floor of the Garcia Trading post would be inundated by about 1 to 2.5 feet of water during a 100-year flood event. The upper floor of the Garcia Trading Post would be 2 to 3 feet above the expected 100-year flood level. A 500-year flood event would inundate all floors of all structures with flood depths ranging from 1 to 5 feet. Worst case flood depths are estimated to be 10 feet above ground level. Such an event, if it occurred, would cause heavy economic damage.

Ground level at the Garcia Trading post would be inundated by about 3 feet of water during the 100-year event and about 6 feet of water during the 500-year flood event. In combination with the velocity estimates of 2 to 4 and 4 to 6 feet per second,

TABLE 3

Predicted 100- and 500-year flood channel velocities in Feet per Second (VEL) for unmitigated and mitigated cases, and flood water surface elevations MSL (WSEL) for the mitigated case in Chinle Wash.

Cross Section Number	Q100 Unmitigated VEL	Q100 Mitigated VEL	Q100 Mitigated WSEL	Q500 Unmitigated VEL	Q500 Mitigated VEL	Q500 Mitigated WSEL
4	5.8	8.8	5,525.1	7.4	12.3	5,527.5
5	7.8	13.1	5,526.9	10.9	16.8	5,530.5
6	8.3	8.7	5,530.4	11.2	11.9	5,534.5

respectively, for these events, adult people would probably be in danger of being swept off of their feet by the flood waters.

A levee of an adequate elevation constructed on the south overbank of Chinle Wash could protect the Garcia Trading Post area from the 100- and 500-year flood events. However, such a structure could increase flow velocities through Chinle Wash by as much as 70 percent for the 100- and 500-year flood events. Increased velocities may alter the existing sediment transport characteristics through Chinle Wash to the point that down-cutting of the channel may occur. Down-cutting of Chinle Wash would increase the risk of levee failure, and possibly alter the downstream flood characteristics of the Wash. The possibility of down-cutting suggests that subterranean toe protection should be considered in the design of the levee. It is also recommended that sediment transport modeling should be conducted for Chinle Wash to further define the impacts of a protective levee if it is pursued as a flood-mitigation alternative. In addition a levee, if not properly designed, may exacerbate flood situations at the Thunderbird Lodge and the NPS campground, as well as to the Garcia Trading Post area by blocking return flows through the historic channel to Chinle Wash. Additional study is needed to develop alternatives for the protection of the Thunderbird Lodge area if a protective levee is selected as a flood mitigation alternative.

Portions of the Chinle Wash floodplain that would be developed by the NPS and the Navajo Nation may be classified as wetlands. Therefore, consultation with the U.S. Fish and Wildlife Service, and/or the U.S. Army Corps of Engineers should be initiated so that a determination can be made on the presence of wetlands and proper mitigation, if needed, can be implemented.

REFERENCES

Abt, S.R., R.J. Wittler, A. Taylor, and D.J. Love, 1989. Human Stability in a High Flood Hazard Zone. Water Resources Bulletin 25(4): 881-890.

Barnes, Harry H., 1977. Roughness Characteristics of Natural Channels. U.S. Geological Survey Water Supply Paper 1849, 213 pp.

Morrison Maierle, Inc., 1977. Navajo Water Resources Evaluation, Volume XII, Flood Plain. Prepared for the U.S. Bureau of Indian Affairs, Navajo Area Office. Window Rock, Arizona.

National Park Service, 1986. Statement for Management, Canyon de Chelly National Monument, Chinle, Arizona. 56 pp.

U.S. Army Corps of Engineers, 1982. HEC-2, Water Surface Profiles, Users manual. Hydrologic Engineering Center, Davis, California.

U.S. Army Corps of Engineers, 1981. Map depicting 100-, 500- year floodplains of Chinle Wash in the vicinity of Canyon de Chelly Headquarters and the Thunderbird Lodge. This document consists of a map only, and is located in the Water Resources Division's permanent files.

U.S. Army Corps of Engineers, 1985. Potential Flooding from Failure of Tsaile Dam. Project Report No. 86-2 prepared for the National Park Service, Canyon de Chelly National Monument. Hydrologic Engineering Center, Davis, California. 49 pp.

U.S. Army Corps of Engineers, Los Angeles District 1989. Navajo Indian Reservation Reconnaissance Study, Technical Report.

Roeske, R.H., 1978. Methods for Estimating the Magnitude and Frequency of Floods in Arizona. U.S. Geological Survey for the Arizona Department of Transportation. Report No. ADOT-RS-15-121. 82 pp.

The National Park Service Water Resources Division is responsible for providing water resources management policy and guidelines, planning, technical assistance, applied research, training and operational support to units of the National Park Service. Program areas include water rights, water resources planning, regulatory guidance and review, hydrology, water quality, watershed management, watershed studies and aquatic ecology.

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As the nation's principal conservation agency, the Department of the Interior has the responsibility for most of our nationally owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people. The department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The mission of the Water Resources Division is to preserve and protect National Park Service water resources and water dependent environments. This mission is accomplished through a watershed management program based on needs at the park, Region, and National levels.

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