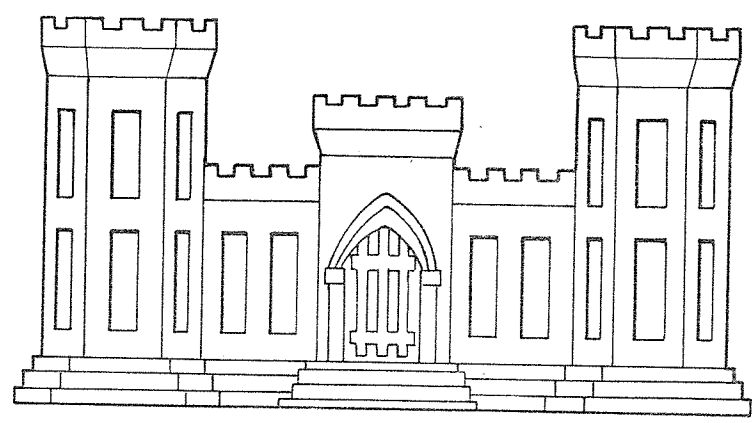


United States Army Corps of Engineers, Sacramento District

HYDRAULIC MINING  
AND  
DEBRIS CONTROL

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SACRAMENTO RIVER  
AND TRIBUTARIES, CALIF.



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HYDRAULIC MINING AND DEBRIS CONTROL  
SACRAMENTO RIVER AND TRIBUTARIES, CALIFORNIA

(Hydraulic mining is defined as mining by means of the application of water under pressure, through a nozzle, against a natural bank. Properly conducted, it is a low-cost mining procedure and with it many large low-grade auriferous gravel deposits not workable by other methods can be made to yield a profit. It has had its place in the affairs of California, first as a means of gold production, then as a source of conflict between mountain and valley interests,) then as a giant crushed and without honor in its own country and finally, as something which at least deserved consideration without the partisan spirit so evident on both sides in the earlier periods.

Practically all of the earlier gold production of California came from gravel in the present day streams, or in ancient river beds. The earliest method of mining was by panning; then came the rocker; the long tom; ground sluicing, and hydraulic mining. The gold bearing gravel adapted to hydraulic mining is principally in the ancient river channels and is known as tertiary gravel from the geological division of time during which the rivers existed. These old river channels were filled with gravel, then covered by lava flows and by other surface transformations, due to geographic development. They have no relation to the present river systems. Often they are high above the existing streams, and have been cut through and exposed in the modern river formation. The location of the old channels well above the present ones is an important factor in hydraulic mining, as grade is made available with which the water used on the gravel bank can carry the resultant debris away from the mine.

It was about the year 1852 that the initial step toward hydraulic mining was taken when a canvas hose and wooden nozzle were used to wash a gravel bank. This method was improved upon by introducing sheet iron pipe and iron nozzles. Canvas remained the means of furnishing a flexible joint until about 1855, when the gooseneck, a flexible iron joint of two elbows allowing horizontal movement, was introduced. Later developments provided for vertical movement and for shifting the direction of discharge, and about 1870 a hydraulic giant comparable with the modern machine came into use. The earlier giants were directed by the difficult procedure of pulling or shoving the nozzle about. An astonishingly simple and effective means of control was discovered in the deflector, however. It is a sleeve fitting over the nozzle and so attached that its outer end can swing into the stream from the nozzle, or the nozzle itself is made so that its tip may be moved slightly either vertically or horizontally. The reaction of the discharge stream swings the giant. With the deflector, a touch is sufficient for control.

An idea of the magnitude of past hydraulic operations may be obtained from observation of the old pits. Some of them extend for several miles and widths of half a mile or more may be noted. In some cases, the depth from surface to bedrock exceeded 400 feet. No less than 6,000 miles of ditches

and 10 miles of tunnels were constructed. Ninety second-feet of water under a 600 foot head, or sufficient energy to develop 4,500 horsepower, has been directed against a gravel bank from a single nozzle, and more than 3,000,000 cubic yards of gravel have been washed from one mine in a single season. Grove Karl Gilbert, in "Hydraulic Mining Debris in the Siorra Nevada's", (U.S.G.S. Professional Paper 105), estimated in 1914, that 1,555,000,000 cubic yards of debris resulted from hydraulic mining in the area tributary to Suisun Bay since 1849 and that over 100,000,000 more came from other forms of mining. Since that time about 11,000,000 cubic yards of debris have been mined by the hydraulic process in the same area. Ordinarily, gold is caught in sluiceways through which gravel from the mine is washed. Riffles or blocks are placed in the sluiceways and provide spaces into which the heavier material, including gold, may settle and lodge. The gold production from hydraulic mining in California is not of record, but an estimate of one billion dollars from all gravel mining is thought conservative.

That the debris problem might be of serious consequence seems to have been first developed by the extreme floods of 1861 and 1862 when large quantities of placer mining and natural debris were brought into the valleys and valley rivers. Continued filling and later scouring in the river beds is shown by variations in low water river levels. At Marysville in 1849, the Yuba River low water level was at about Elev. 37, U.S.G.S. datum. In 1873 it was 10 feet higher, and a peak was reached about 1905 when it was 19 feet higher. In 1928 it had receded to approximately the 1873 level and since then has dropped about 5 feet more. At Sacramento the Sacramento River low water level in 1849 was about mean sea level. From 1880 to 1905 it was about 7 feet higher and by 1928, had dropped back to about the 1849 level.

The first concerted action against hydraulic mining came with the formation of the Anti-Debris Association in the early seventies and about 1876 the first suit was decided against the miners. Hydraulic mining was finally stopped by court injunction in 1884 after a long and bitter fight between mining and valley interests. At that time there was no general effort to control the tailings, and the valley lands were suffering serious damage from inroads of the debris. Thereafter hydraulic mining on the drainage area of the Sacramento and San Joaquin Rivers was not possible, except under cover, until authorized under regulation by the California Debris Act in 1893. During the period of prohibition, "bootleg" mining occurred, but few of the mining companies remained alive. Water systems and equipment deteriorated greatly and heavy expenditures were necessary before mining could be resumed.

The California Debris Act was the result of efforts of mining interests to do something for hydraulic mining. It was "an act to create the California Debris Commission and Regulate Hydraulic Mining in the State of California", and required that a commission composed of three officers of the Corps of Engineers, U. S. Army, be appointed by the President. The commission was to make plans and estimates for the improvement of the navi-

gable rivers affected by hydraulic mining or other debris, and to permit hydraulic mining, provided it could be accomplished without injury to the navigability of the rivers or adjacent lands. The act also required study and research for practical methods whereby mining could be carried on without injury to the interests under protection.

The Commission's first efforts toward control of debris were centered upon the Piedmont deposits of the Yuba River where the most threatening volume of debris had accumulated.

Since passage of the Debris Act, about 1,200 applications for mining licenses have been filed with the Commission, and about two-thirds of them were able to obtain licenses. Most of the others were unable to provide requisite debris storage or for financial reasons, did not go ahead. Storage of debris so that it cannot later get into navigable streams, is the principal condition of operation, and generally, fairly large storage developments are desirable because of relatively small unit storage costs. Such developments are seldom possible for the average mine because of the high initial investment.

Debris storage, except as individually developed, is now available to hydraulic mines at only one place. This is in the Pacific Gas and Electric Company's Bullards Bar Reservoir on the North Yuba River about three miles above the mouth. The dam is 175 foot high, was built in 1924, and provides for power development as well as debris storage. The reservoir has a water storage capacity of 31,500 acre foot or about 50,000,000 cubic yards. About 40,000,000 cubic yards of debris storage space is available and is sold at two cents per cubic yard as measured in place at the mine.

The Nevada Irrigation District built the Combe Dam on the Bear River in 1928. It is about 37 miles above the river's mouth and about  $3\frac{1}{2}$  miles west of Clipper Gap, a Southern Pacific Railroad Station. Debris storage space in the reservoir was sold to mines above, until mining was stopped by a court decision. In this case, water was diverted from the river at a point between the mines and the reservoir, and before there was an opportunity for debris settlement. Further use of the storage space is dependent upon a workable plan to care for conflicting interests.

Since the formation of the California Debris Commission, a number of reports have been made upon the practicability of debris storage developments which would permit at least a partial rehabilitation of hydraulic mining, and would eliminate the objectionable features of the former operations. Preliminary studies developed various factors requiring consideration.

Opposition to any renewal of hydraulic mining was principally from the valley counties through which the debris receiving rivers flow. The damage done by previous mining was pointed out. The possibility of regulating the mines if they start operating again, of holding the debris where

it would do no harm, and the advisability of using storage space which would otherwise be available for water, were questioned. It was also stated that mining would not pay in any event if it had to carry all expenses and, therefore, that debris storage provision would be a direct subsidy to the mines.

Mining interests argued that Federal and State aid was justified because a \$100,000,000 investment had been wiped out when mining was stopped by Federal court injunctions; that governmental expenditures for the mining industry would be similar to those for agriculture, that large amounts of much needed gold would be obtained, that the expenditures would be repaid, that the mining would be conducted under regulations and without harm to others, and that new markets and additional employment would result. It was also stated that excavation in mining would leave large pits which could be adapted to water storage when mining was finished and that the water systems built for mining could be made to serve the reservoirs.

The most recent reports upon the hydraulic mining situation are listed as follows:

(a) Report of the Hydraulic Mining Commission upon the feasibility of the Resumption of Hydraulic Mining in California. (A report to the California State Legislature of 1927).

(b) Hydraulic Mining Investigations in California. Senate Doc. 90, 70th Congress, 1st Session (California Debris Commission report submitted to the Chief of Engineers, U. S. Army, in January, 1928).

(c) Sacramento River and Tributaries, California (Debris Control). Committee of Rivers and Harbors, H. of R. Doc. 50, 74th Congress, 1st Session. (California Debris Commission report submitted to Chief of Engineers, U. S. Army, in February, 1935).

In August, 1935, Congress adopted a project which is described in the Doc. 50 referred to above, for the development of hydraulic mining debris storage in the Yuba, Bear, and American Rivers, at an estimated cost of about \$7,000,000.00. The project contemplates a dam 237 feet high on the Main Yuba River at the Upper Narrows Dam Site which is about 2 miles northeast of Smartville and about  $\frac{3}{4}$  mile above the mouth of Deer Creek. The storage will provide for 118,000,000 cubic yards of new mining debris and the estimated cost is \$4,595,000.00.

The dam on the North Fork of the American River at the North Fork site, about 2 miles above the junction of the North and Middle Forks, will be about 139 feet high and will provide for 26,000,000 cubic yards of new mining debris at an estimated cost of \$900,000.00. A dam on the Middle Fork of the American River at the Ruck-A-Chucky Dam site, is about  $10\frac{1}{2}$  miles above the junction of the Middle and North Forks on the American River, and just below the mouth of Canyon Creek, will store 24,000,000 cubic yards of debris and will be about 148 feet high. The cost estimate is \$750,000.00.

While the project includes a dam at the Dog Bar site on the Bar River, about 6 miles above the Combe Dam, its construction at the present time is inadvisable because of the court decision which prevents operation of the most important mines in the drainage area. The proposed dam would be 122 feet high, would restrain 26,000,000 cubic yards of debris, and the cost was estimated at \$1,130,000.00.

It is estimated that the value of recoverable gold in the gravels, mineable under the project, ranges from 15 to 25 cents per cubic yard, also that recovery can be accomplished for from 10 to 18 cents, with an average not in excess of 12 cents.

The California Debris Commission will construct the debris dams and will collect a tax upon each cubic yard of gravel mined. The tax in each case will be equal to the total capital cost of the dam and reservoir divided by its debris capacity in cubic yards. It is estimated that the capital cost without interest, will be returned over a 20-year period, and that federal and general benefits, including those to navigation because of the restraint of more than 20,000,000 cubic yards of natural erosion and old mining debris will fully justify the exclusion of interest charges.

Economic power development will be possible at the Upper Narrows site and provision therefor is to be made in the dam design; actual accomplishment being dependent upon desirable power disposal arrangements.

Foundation studies including borings, surface cuts, and tunnels, have been and are being carried on at the Upper Narrows and the two American River sites. This exploratory work has been completed at the Upper Narrows and North Fork sites and is still in progress at the Ruck-A-Chucky site.

Bids on the construction of the North Fork Dam will be received about April 1, 1938.

The North Fork Dam site is situated in a narrow, rocky gorge with very little overburden on the right bank. Soil cover extends to a greater depth on the left bank and is underlaid by fractured rock to a total depth averaging 35 feet below the surface from crest elevation to approximately 30 feet above low water. Below this elevation good bedrock is found at shallow depth. The stream bed section contains river-borne sand and gravel with a maximum depth of about 16 feet. The rocks at this site are ancient metamorphosed lavas and are classified as meta-andosite, meta-andesite breccia, and meta basalt. All of these rocks are dense, hard, and massive, and capable of withstanding far greater loads than would be imposed upon them by an engineering structure.

Geological exploration of the site was undertaken to determine sub-surface conditions. Two tunnels were driven into the rock on the left bank to intercept the foundation of the dam. After passing through the broken and weathered rock underlying the overburden, the tunnels entered fresh rock with only very minor jointing and no oxidation or weathering. Two tunnels

ore driven into the right abutment and at comparatively shallow depth encountered fresh rock.

Exploration of the streambed section of the site was conducted by diamond drill borings. Three vertical holes were sunk through the streambed gravel and drilled into the bedrock to a depth of about 35 feet below the bedrock surface. In addition to these vertical holes, inclined holes were bored on approximately the line of the vertical holes to intersect under the streambed section. Examination of the cores from these drill holes showed that there were no sheared or crushed zones underneath the streambed section nor any evidence of faulting. Due to the comparatively small span at crest elevation compared to the height of dam, a single arch type structure was chosen for this location.

The Ruck-A-Chucky dam site is in a broad belt of rock classified as amphibolite schist. This rock, in addition to its characteristic schistosity; has, in many parts of the canyon, been subjected to deep weathering due to the presence of numerous fractures and joints. Considerable exploratory work has been necessary due to these weaknesses in the formation. Near the upper end of the canyon, outcroppings of more massive rock occur with little surface indication of these defects. The exploratory work now being prosecuted contemplates developing the extent and depth of this more massive formation. It is believed at this time, that satisfactory rock can be developed at a reasonable depth at this site.

The streambed section has been explored in the same manner as that used at the North Fork Dam site. While excavation in the streambed section must of necessity, be carried to greater depths than at North Fork, it appears that satisfactory rock will be found which will be capable of withstanding the vertical loads to which it will be subjected. As this site has approximately the same crest span and height above streambed as the North Fork site, a single arch dam will be used.

The Upper Narrows dam site is located in a comparatively narrow canyon composed of ancient metamorphosed lavas. These rocks are quite similar in many respects to those exposed at the North Fork dam site. The geology of this site is quite complex. Many alternating bands of different formations intersect the river channel at approximately 45°. Although different in texture and composition, any of these rocks are suitable for construction of a high dam within reasonable depths of excavation.

The left abutment rises at a steep angle from the horizontal, and presents good rock exposures from streambed to crest. Stripping requirements on this side will be limited largely to the removal of surface blocks and to preparing abutments for the dam. The right abutment shows good rock exposures to approximately 40 feet above low water. From this elevation upwards the depth to satisfactory rock increases considerably. A large part of the upper portion of the right abutment has soil cover and fractured and decomposed rock varying in depth from 20 feet to a maximum in one place

of over 60 feet. Tunnels excavated into the right abutment have shown, however, that dense, strong, and durable rock in sufficient mass to support the dam will be encountered. The streambed section was explored by diamond drilling in the same manner as at the other two sites. The depth of gravel in the streambed section reaches a maximum of approximately 10 feet.

One very prominent feature at this site, both geologically and topographically, is an ancient fault which crosses the streambed at an acute angle. This fault intersects the location of the dam in the area between low water and high water elevations. Below the dam site a diamond drill hole intercepted this fault and showed less than a foot of brecciated material. Another diamond drill hole crosses this fault on about the axis of the dam. This drill hole, at its interception with the fault, is about 30 feet above low water elevation. Here oxidation along the fault has proceeded until the unsatisfactory material encountered by the drill hole is approximately 4 feet thick. At about 10 feet below high water elevation a tunnel was driven between the two walls of the fault. The filling material in the fault shows no evidence of gouge. In the drill holes which intercept the fault and in the drift along the fault, minerals have been deposited which indicate that the fault has been inactive for many thousands of years. The consulting geologist, Dean George D. Louderback, of the University of California, has stated that in all probability there has been no activity on this fault in recent geologic time, and that renewal of activity along this fault is not to be expected. At this site it is proposed to construct a single arch dam similar in many respects to the two dams to be built on the American River.

All three of these sites are particularly suitable for the construction of single arch dams. Comparative cost estimates show that these dams can be constructed at a great saving over concrete gravity dams. Due to the heavy flood flows at all three sites, the cost of spillways and diversion works for rock fill dams made that type of structure prohibitive in cost.

Since the large majority of single arch dams constructed in the United States have been built in the far west, a description and short history of this type of structure is of interest. The basic conception of the single arch dam is that it consists of arches, circular in horizontal section at all elevations. Unlike the gravity dam, the stability of an arch dam is dependent upon the strength of the concrete used in its construction rather than upon its weight.

The arch dam is not a new development. The first arch dam of which there is any record was constructed in Italy in the year 1611. This was the Ponte Alto Dam near Trentino. It occupied a narrow canyon and was built of cut stone masonry. The original height was 16 feet, but the dam was raised from time to time until in 1887 it had reached a height of 124 feet. In spite of the materially increased hydrostatic head upon the lower part of the dam, this portion was never reinforced.



In spite of this early experience, the real development of arch dams began in the latter part of the 19th century. During this period a number of this type were built in Italy, and a few were built in this country and in Australia. Of all arch dams, the highest arch dam built prior to 1900, was Ponte Alto, Italy, closely followed by Sweetwater Dam. The latter has since been increased in section until it now stands as a gravity structure.

With the dawn of the new century, the design and construction of arch dams took on new impetus. Typical examples are the Pathfinder Dam, 210 feet high and Shonshone Dam, 328 feet high. These were built by the United States Reclamation Service between 1905 and 1910. Other dams were Lake Spaulding, in California, which has twice been raised until it is now 275 feet high; Bullard's Bar Dam near Marysville, built in 1923 to a height of 183 feet; and Cushman Dam, 280 feet high, built in 1925 for the City of Tacoma. Finally, such structures have been built as the Pacoima Dam of the Los Angeles County Flood Control District, completed in 1928 to a height of 370 feet, and Diablo Dam of the City of Seattle, completed in 1931 to a height of 389 feet.

The earlier arch dams were generally built with a vertical upstream face having a constant upstream radius from crest to base of dam. In these earlier designs, the stresses due to water load were assumed to be the same as those for a thin cylinder, that is, that the stress in any horizontal arch ring 1 foot in height was equal to the pressure on the extrados multiplied by the radius of the upstream face and divided by the thickness. No account was taken of the stresses due to rib-shortening of the arch under load, nor of the stresses due to changes in temperature.

About 1912, another type of the single arch dam made its appearance which was destined to play a large part in the development of arch dams. Using the so-called cylinder formula as a means of determining stresses in the arch, Mr. L. R. Jorgensen, Member, American Society of Civil Engineers, found that for an arch of given span, unit water load and stress, the minimum volume of concrete in the arch was obtained when the subtended angle of the arch was  $133\frac{1}{2}^{\circ}$ . He also showed that for a change in central angle of  $15^{\circ}$  either way, the relative volume was changed but a small amount. With this as a basis for design, he proposed to make the central angle of the horizontal arches at all elevations as nearly as possible constant by decreasing the radii of the arches progressively from crest of dam to base. He gave to this type of dam the name constant angle arch dam.

Mr. Jorgensen's idea was prompted entirely by motives of economy in dam construction, but this principle was to have even more importance on the design of arch dams, when more rational formulae were used in stress determination. The cylinder formula was still used extensively in arch dam analysis, but about 1920 it began to fall into ill repute. Various means of analyzing arch dams had found their way into technical literature, particularly the publications of the American Society Civil Engineers. In the various methods of analyses proposed about 1921, the authors of these papers gave consideration to the deformation of arches under load and the