Apache Comments

EPA HQ: No comments, CD/JM

EPA Region:

See attached document date Nov. 17, 2009

State:

From: "Michael J. Johnson" <mjjohnson@azwater.gov>
To: James Kohler/DC/USEPA/US@EPA, John Schofield/R9/USEPA/US@EPA, 'Mel P.Bunkers' <Bunkers.Mel@azdeq.gov>
Cc: Stephen Hoffman/DC/USEPA/US@EPA, Ravi Murthy <rmurthy@azwater.gov>, "Karen L. Smith" <klsmith@azwater.gov>
Date: 11/09/2009 11:40 AM
Subject: RE: Comment Request on EPA's Draft Coal Ash Impoundment Assessment Reports

Jim,

Thanks for the opportunity to review the reports. ADWR has no direct comments on the reports themselves. Please be advised that following our next inspection of the state-regulated dam at the Apache site (tentatively scheduled for December 2009), we will review the current earth fissure mitigation plan in light of more recent findings related to fissure monitoring and identification at other Arizona damsites.

Mike

Michael Johnson, Ph.D., P.E.
Assistant Director, Surface Water Division
Arizona Department of Water Resources
(602) 771-8659
mjjohnson@azwater.gov

From: "Mel P. Bunkers" <Bunkers.Mel@azdeq.gov>
To: James Kohler/DC/USEPA/US@EPA
Date: 11/20/2009 11:43 AM
Subject: RE: Comment Request on EPA's Draft Coal Ash Impoundment Assessment Reports

Jim,

I have no comments at this time.

Thanks,

Mel Bunkers, Manager
Hazardous Waste Inspections and Compliance Unit
Arizona Department of Environmental Quality
1110 W Washington Street
Phoenix, Arizona 85007
Phone: (602) 771-4556
Fax: (602) 771-4132

<u>Company</u>:

See attached letter dated November 24, 2009 and four (4) enclosures (comment document, 0.5 PMP Event Design Basis, ADWR License of Approval, Three-foot freeboard support calculations).

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IX
75 Hawthorne Street
San Francisco, CA 94105

November 17, 2009

MEMORANDUM

SUBJECT: Comments to *Draft Final* Specific Site Assessment for Coal Combustion Waste Impoundments at Arizona Electric Power Cooperative (AEPCO) Apache Power Plant, Prepared by GEI Consultants, Inc., dated October 2009

FROM: John Schofield, RCRA Enforcement Office

TO: James Kohler, P.E., Office of Resource Conservation of Recovery

The following are EPA Region IX, RCRA Enforcement Office comments to the referenced report:

1. Page 26, 7.2 Inflow Design. The term “PMP” should be defined.

2. Page 26, 7.2.1. The term “PMF” is used in the title of this report and the term PMP is used in the subsection of the report. The discussion of this subsection should be expanded to include relationship between PMP and PMF, and any calculations GEI performed to verify the PMF.

3. Page 39, 12.5. The condition of the management units in this section of the report was determined by GEI Consultants, Inc. (GEI) as “Fair.” It is not clear from the report what observations/findings were the basis of GEI’s condition assessment determination. Recommend that GEI summarize which findings/observations lead to the company’s condition determination.

Arizona Electric Power Cooperative, Inc.

P.O. Box 670 • Benson, Arizona 85602-0670 • Phone 520-586-3631

VIA E-MAIL

November 24, 2009

Mr. Stephen Hoffman
Office of Resource Conservation and Recovery (5304P)
U. S. Environmental Protection Agency
1200 Pennsylvania Avenue, NW
Washington, D.C. 20460

RE: AEPCO RESPONSE TO EPA SITE ASSESSMENT REPORT

Dear Mr. Hoffman:

Arizona Electric Power Cooperative, Inc. appreciates the opportunity to review and comment on the "Draft Final – Specific Site Assessment for Coal Combustion Waste Impoundments at Arizona Electric Power Cooperative (AEPCO) Apache Power Plant" (the "Assessment") completed by GEI Consultants, Inc in October 2009.

AEPCO appreciated the opportunity to have the U.S. Environmental Protection Agency (EPA) on site for the inspection. AEPCO has always and will continue to maintain a high performing facility to ensure the safety of our employees and neighbors are first priority. Given our excellent compliance history and proven track record, as well as GEI's verbal assessment of our facility following the inspection, AEPCO respectfully requests that the Assessment be revised to rate our facility "Satisfactory," as further discussed in our attached comments. We look forward to working with EPA and its consultants during this review period.

If you have questions regarding the content of these comments, please contact me at 520-586-5122 or mfreeark@ssw.coop.

Sincerely,

Michelle R. Freeark
Manager of Environmental Services

Attachments

cc: File: CERCLA/EPA Ash Pond Inspection/2009 w/ enc.

AEPCO Comments on GEI Draft Report

Specific Site Assessment for Coal Combustion Waste Impoundments
Arizona Electric Power Cooperative (AEPCO) Apache Power Plant
Cochise, AZ
Dated October 2009

Page 1, Section 1.1

General Comment – Please note that the impoundments are referred to by GEI as AP1, AP2, AP3, AP4 , SSP1, and SSP2. All AEPCO documentation uses Ash 1, Ash 2, Ash 3, Ash 4, Scrub1, and Scrub 2. This may be confusing to anyone referencing both GEI and AEPCO documents in the future.

Page 6, Section 2.7 – Second paragraph

Change the third sentence to read "An old ash and scrubber waste disposal facility that is no longer in service has been closed through Arizona DEQ and the ADWR Flood Warning and Dam Safety Section."

Page 8, Section 3.0 – First paragraph

Change the third sentence to read "An old ash and scrubber waste disposal facility that is no longer in service has been closed through Arizona DEQ and the ADWR Flood Warning and Dam Safety Section."

Page 8, Section 3.0 – Fourth paragraph

Need to clarify sixth sentence – the site had not been disturbed except for surface farming.

Page 13, Section 6.2 – Seventh sentence

Correct the description of Ash Pond 1 to be consistent with Ash Pond 2 description in section 6.3, page 15. The bottom of the cell is lined with a 60-mil HDPE liner and the sides are lined with 80-mil HDPE.

Page 24, Section 6.9.4

AEPCO suspects that minor damage has been caused by vandalism and wildlife. Additionally, the report mischaracterizes the condition of the SSP2 Liner. AEPCO indicated to GEI that there has been minor damage to the SSP2 Liner in the past which has been properly repaired by outside vendors. The report, however, states that there are similar instances of damage to the lining of the other ponds. This language should be revised to more accurately reflect the condition of the liners by replacing the sentence referring to "other ponds" with the following: "AEPCO indicated during the inspection that there had been minor damage to the SSP2 Liner only."

Page 26, Section 7.2 – First paragraph

Spell out PMP acronym for first time use.

Page 26, Section 7.2 – Second paragraph

GEI states that the ponds were designed to hold the 11.2 inch NOAA Probable Maximum Precipitation (PMP) Event. This statement is incorrect. The correct design value was ½ PMP (see attached Burns & McDonnell sheet). Additional freeboard adequacy calculations, performed in 1997 at ADWR's request, are attached herein. The calculations illustrate that a three-foot-freeboard is adequate to contain a 9.6 inch rain event (more than a ½ PMP Event), including wind tide and wave heights generated from 55 mph winds without overtopping the dike crests. The facility is permitted to operate at a three-foot-freeboard (evaporation pond freeboard is 3.5 feet) by the Arizona Department of Water Resources (License number 02.03) and the Arizona Department of Environmental Quality (Aquifer Protection Permit number P-101494). A copy of the ADWR License of Approval, with freeboard levels specifically stated on the permit, is attached herein. Any language suggesting that the facility does not maintain adequate freeboard should be deleted. This comment applies to Sections 7.2.2 and 7.4 later in the report.

Page 26, Section 7.2.3 – First Sentence

Rewrite the first sentence to read "A simplified dam break analysis and inundation mapping was completed by Burns & McDonnell for the facility."

Page 28, Section 8.2 – Second bullet

Correct first sentence to read "In 1974, Burns & McDonnell performed a subsurface investigation at the location of the proposed power plant for steam units 2 & 3."

Second sentence appears to be missing reference to a specific report.

Page 28, Section 8.2 – Third bullet

Last sentence appears to be missing reference to a specific report.

Page 30, Section 8.5 – Table 8.1

Rapid Drawdown – Water Depth at 27 feet is reported to have a FOS of 0.74. These calculations were performed assuming the facility had no HDPE liner in place. This FOS is increased considerably by the HDPE liner being in-place on the upstream sideslope, as indicated by GEI's statement in the second paragraph of Section 8.8.1.

Page 33, Section 9.3 – First sentence

GEI states that the entire project is patrolled daily by APS personnel. AEPCO is confused by this reference to APS, and is concerned that GEI has confused AEPCO's facility with Arizona Public Service's ash pond facilities. Additionally, the AEPCO facility is patrolled every two hours by security personnel and on a daily basis by operations.

Page 34, Section 10.0 – Fourth paragraph

General Comment – Please note that the cooling tower blowdown is referred to by GEI as CTB. All AEPCO documentation uses CTBD. This may be confusing to anyone referencing both GEI and AECPO documents in the future.

Page 36, Section 11.1.3 – First paragraph

Refer to Section 7.2 comments above.

Page 38, Section 12.3
GEI states AEPCO needs to address inadequate freeboard. Refer to Section 7.2 comments. GEI states that automatic pump shutoff controls should be provided. AEPCO feels it would be of little benefit to install automatic pump shutoff controls compared to the cost of installation and maintenance. Normal operation of the ash ponds includes recirculation of pond water to the plant to sluice ash back to the ponds. This operation method ensures that outflow always equals or exceeds inflow to the ash ponds. Normal scrubber slurry waste disposal flows to the scrubber waste storage ponds are 100 gallons per minute (gpm). Although this water is not recycled, it would required 41 hours at normal disposal flow rates to the one active scrubber waste storage pond to raise the pond level one foot. However, AEPCO is investigating using the common Ash Pond Recirculation Water sump for passive freeboard level control. Excess water from Ash Ponds 1 & 2 would overflow to Ash Ponds 3&4 which are not currently in-service and have a large freeboard available. In the same manner, AEPCO is investigating using a standpipe attached to the HDPE piping between Scrubber Ponds 1 & 2 to send excess water to Scrubber Pond 2 which is not currently in-service and has a large freeboard available. Any language suggesting that the facility does not maintain adequate freeboard should be deleted.

Page 38, Section 12.4
Section titled "Any New or Additional Monitoring Instruments…" - paragraph 1 – These comments are not new or additional to what AEPCO is already performing. This paragraph should be deleted. Third paragraph – GEI has recommended installing observation wells or piezometer instrumentation. These items are not normally designed into or installed in ash ponds by consulting engineering firms. These items are usually installed after leaks, pooling or seepage is discovered. Each dike of the AEPCO facility is a dam, and as such, observation wells and piezometers would need to be installed along all exterior and interior dikes. AEPCO believes this to be a generic comment by GEI. If seepage, water pooling at dike toes, or significant HDPE liner leaks are discovered in the future, AEPCO would then consider installation of observation wells or piezometer instrumentation.

Page 39, Section 12.5
Section 11.2 of the GEI report states that "The seven impoundment dams were generally found to be in satisfactory condition". In Section 12.5, GEI give the ponds a "FAIR" rating. Verbal comments from GEI personnel in the site meeting and inspections, including the debrief, indicated that the ponds were satisfactory. AEPCO is confused that GEI gave a satisfactory rating to the facility in the exit debrief, refers to the facility as satisfactory in Section 11.2, and then assesses the ponds as "FAIR" in Section 12.5. The ADWR Flood Warning and Dam Safety Section report dated December 19, 2008, states that there are no existing safety deficiencies with the AEPCO facility. AEPCO maintains that our facility should be assessed "SATISFACTORY", based upon GEI's verbal comments, report text, and AEPCO's highly performing staff, operations, maintenance, testing program, and past record with permitting agencies. As such, the report should be revised to assess the facility as "Satisfactory" consistent with GEI's verbal assessment and the facility's performance.

Appendix B

Coal Combustion Waste (CCW) Impoundment Inspection Form for Ash Pond No. 1, 2, 3, 4 and Scrubber Waste Storage Ponds – page 3 – Liner Permeability for clay is incorrect. Correct permeability is 1 x 10EE-6 cm/s.

Coal Combustion Waste (CCW) Impoundment Inspection Form for Ash Pond No. 1, 2, 3, 4 and Scrubber Waste Storage Ponds – page 4 – Impoundment design date is incorrect. Correct date is 1994.

6.0 FREEBOARD CAPACITY FOR A 0.5 PMP STORM EVENT

The probable maximum precipitation (PMP) depth for this area in Arizona is approximately 11.2 inches based on information in the National Oceanic & Atmospheric Administration (NOAA) Hydrometeorological Report No. 49. The 0.5 PMP would be approximately 5.6 inches. All of the ponds are designed to exclude offsite runoff from entering and to maintain a minimum freeboard of 3 feet. Therefore, if the 0.5 PMP were to occur, there exists adequate freeboard to prevent discharge over the dike crest.

cc C Walling / Dam   XC: 923001 - Permits
923001 - Corp. Rec.

ARIZONA DEPARTMENT OF WATER RESOURCES
Dam Safety Section
500 North Third Street, Phoenix, Arizona 85004-3903
Telephone (602) 417-2445
Fax (602) 417-2423

Chuck: please let me know what you would like to do with the original gold seal license.
Thanks
Chuck Reece
x 5120

August 25, 1997

Mr. Charles S. Reece IV, P.E.
Arizona Electric Power Cooperative, Inc.
Post Office Box 670
Benson, Arizona 85602-0670

Subject: Apache Station Ash/Scrubber Waste Disposal Facility Dam (02.03)
License of Approval

Dear Mr. Reece:

All statutory requirements in connection with the construction of the Apache Station Ash/Scrubber Waste Disposal Facility Dam have now been satisfied. Accordingly, enclosed is a License of Approval to operate the dam. The license outlines the terms and conditions, discussed with you by telephone, under which continued operation of the dam is permitted. This license supersedes any previous operating consent issued by the Department.

During the course of normal operation of your dam, Department engineers will inspect it periodically to confirm that it is being operated and maintained properly. We will contact you in advance of each regularly scheduled inspection to coordinate a mutually satisfactory inspection date. The next regular inspection is currently scheduled for November 1998. In the interim, please contact us immediately should you observe any unusual or alarming circumstances that may adversely affect the safety of the dam.

You may contact Mike Greenslade of our Flood Warning and Dam Safety Section at (602) 417-2400, Extension 7188, if you have any questions. Thank you for your cooperation.

Sincerely,

Dan Roger Lawrence, P.E.
Manager
Dam Safety Section

Enclosure

CC: Donald W. Kimball, AEPCO w/o encl.

State of Arizona
DEPARTMENT OF WATER RESOURCES

LICENSE OF APPROVAL

Pursuant to Title 45 - Waters, Chapter 6, Article 1, of the Arizona Revised Statutes, the DIRECTOR, Department of Water Resources issues this License of Approval to:

ARIZONA ELECTRIC POWER COOPERATIVE, INC.

Authorizing the use of: APACHE STA. ASH/SCRUBBER WDF *Dam and Reservoir, File Number:* 02.03

Located in Section 4 *, Twp.* 16S *, Rge.* 24E *, G. & S.R. B. & M.,* COCHISE *County, State of Arizona, to impound water in accordance with and subject to the following conditions:*

1. The maximum operating water levels shall be: Ash Disposal Pond Cells at elevation 4213.0 ft.; Scrubber Sludge Pond Cells at elevation 4223.0 ft.; Evaporation Pond at elevation 4212.5 ft.
2. An instrumentation monitoring report shall be submitted to ADWR annually in February in accordance with the approved "Embankment Dikes Monitoring Plan", dated December 12, 1996.

This License of Approval supersedes every previous consent for use issued by the State of Arizona relative to said dam and reservoir.

Witness my hand and seal of the Arizona Department of Water Resources

this 25th *day of* AUGUST , 1997

Darrell Jordan

Darrell Jordan
Assistant Director
Surface Water Management Division

Arizona Electric Power Cooperative, Inc.

P.O. Box 670 • Benson, Arizona 85602-0670 • Phone 520-586-3631

May 27, 1997

Mr. William C. Jenkins, P.E.
Arizona Department of Water Resources
500 N. 3rd St.
Phoenix, AZ 85004

RE: COMBUSTION WASTE DISPOSAL FACILITY W.O. 923001/933148
PROJECT NO. 91-033-1-010
CONTRACT 923001-2 - POND AND APPURTENANCES CONSTRUCTION
INDIVIDUAL POND WAVE HEIGHT, SETUP, & RUNUP CALCULATIONS

Dear Mr. Jenkins:

In accordance with your Mr. Gerald Cox's request, enclosed are the subject matter. These are in support of AEPCO's request to allow a maximum reservoir height of three feet below the dike crest (4213' for ash disposal & 4223' for scrubber sludge disposal ponds) for all disposal ponds, with exception of the evaporation pond. Please review these calculations at your earliest convenience and let me know at (520)586-5120 should you have any questions or need additional information concerning the issuance of an Approval to Operate for the Facility.

Sincerely,

Charles S. Reece IV, P.E.
Mechanical Engineer

enc

xc C. Davis, w/o enc
L. Huff, w/o enc
rt G. Grim, w/enc
C. Walling, w/enc
File 923001-ADWR, w/enc

S:\POWER\GENENGR\CHUCK\923001\ADWR\WAVEHGT.WP5

AEPCO | C.S. Reece IV | 5/27/97 | 1/2

Significant wave height

$Z_w = 0.034\ V_w^{1.06}\ F^{0.47}$ ②

where Z_w = average height of highest 1/3 wave

V_w = wind velocity (miles/hr) = 55 mph ①

F = fetch (miles)

Z_w Table		Fetch (ft)	(miles)	Z_w (ft)
Ash Pond	1	1,560	0.295	1.34
	2	1,570	0.297	1.34
	3	1,700	0.322	1.40
	4	1,870	0.354	1.46
Scrubber Pond	1	1,880	0.356	1.46
	2	1,880	0.356	1.46

Add wind tide to wave height calculations for maximum wave height and runup

See page 2 for wind tide calcs.

originals to file, copies to ADWR

Wind tide or set-up calculation

$$S = \frac{U^2 F}{1{,}400\ D} \quad (3)$$

where S = wind tide (feet)
U = avg. wind velocity (mph)
F = fetch (miles)
D = avg depth along fetch line (feet)

(see previous pages for wind vel. & fetch)

S Table

		Avg Depth Along Fetch (ft)	Wind Tide (feet)
Ash Pond	1	27	0.02
	2	27	0.02
	3	27	0.03
	4	27	0.03
Scrubber Pond	1	11	0.07
	2	13	0.06

Add wind tide height to wave height calculation

Calculation of wave period & wave length

$$T_w = 0.46\ V_w^{0.44}\ F^{0.28}$$

where T_w = wave period

$$\lambda = 5.12\ T_w^2$$

where λ = wave length (feet)

Calc table

		T_w	λ	Z_w/λ
Ash Pond	1	1.91	18.7	0.07
	2	1.91	18.7	0.07
	3	1.95	19.5	0.07
	4	2.01	20.6	0.07
Scrubber Pond	1	2.01	20.6	0.07
	2	2.01	20.6	0.07

Embankment slope = 1/3 = 0.333

From Figure 7.13 ②

Relative Run up $\frac{Z_r}{Z_w} = 1.48$

thus Z_r = wave runup (vert) (ft)

$Z_r = 1.48\left(Z_w + S\right)$ (see next page for S)

Z_r table		Z_w (ft)	S (ft)	Z_r (ft)	IDF (ft)	Pond Height Below Crest (IDF + Z_r) (ft)
Ash Pond	1	1.34	0.02	2.01	0.8	2.81
	2	1.34	0.02	2.01	0.8	2.81
	3	1.40	0.03	2.12	0.8	2.92
	4	1.46	0.03	2.21	0.8	3.01
Scrubber Pond	1	1.46	0.07	2.26	0.8	3.06
	2	1.46	0.06	2.25	0.8	3.05

Note: IDF is maximum inflow design flood which is 1/2 of predicted maximum precipitation or 0.8 ft

From the previous calculations, it may be concluded that a maximum pond level of three feet below the crest will not produce waves which overtop the dike. Maximum pond heights would be 4213' (4216-3) and 4223' (4226-3) for ash and scrubber sludge disposal ponds, respectively.
(see B&M Design Notes & Analysis for Comb, Waste Disposal Facility for Evaporation pond wave runup calculations)

References:

① B&M Design Notes & Analysis for ... Ponds
② Water Resources Engineering
③ Hand book of Applied Hydraulics

Burns & McDonnell
ENGINEERS - ARCHITECTS - CONSULTANTS
Kansas City, Missouri

Client: AEPCO
Page 1 Of 1
Project No. 91-033-1-010 Date 3/20/92 Made By MKF
7.2 WAVE RUNUP Checked By KGC/TZL
WAVE RUNUP CALCS Preliminary ____ Final ____

ASSUMPTIONS: - 55 MPH DESIGN WIND SPEED
- FETCH LENGTH ≈ 2800 L.F. = 0.53 MILES
- PREVAILING WIND DIRECTION = SOUTHEAST TO NORTHWEST
- DESIGN SOURCE "WATER-RESOURCES ENGINEERI

SIGNIFICANT WAVE HEIGHT

$Z_w = 0.034 V_w^{1.06} F^{0.47}$ V_w = WIND VELOCITY

$= 0.034(55)^{1.06}(0.53)^{0.47}$ F = FETCH (IN MILES)

Z_w = AVG HEIGHT OF HIGHEST ⅓

= 1.76 FT ✓ = SIGNIFICANT WAVE HEIGHT

MINIMUM TIME DURATION OF WIND VELOCITY = 10 MIN

RELATIVE RUN-UP

Wave Period → $T_w = 0.46 V_w^{0.44} F^{0.28}$

$= 0.46(55)^{0.44}(0.53)^{0.28}$

= 2.25 ✓

WAVE LENGTH → $\lambda = 5.12 T_w^2$

$= 5.12(2.25)^2$

= 25.92 ✓

VALUE OF $\frac{Z_w}{\lambda} = \frac{1.76}{25.92} = 0.068 \approx 0.07$ ✓

EMBANKMENT SLOPE $= \frac{1}{3} = 0.333$ ✓

FROM FIGURE 7-13:

RELATIVE RUN-UP $\frac{Z_r}{Z_w} \approx 1.48$

VERTICAL HEIGHT OF RUNUP: $Z_r = 1.48(1.76)$

= 2.6' ✓

LENGTH OF RUNUP ALONG SLOPE = 2.6(3)

= 7.8' ✓

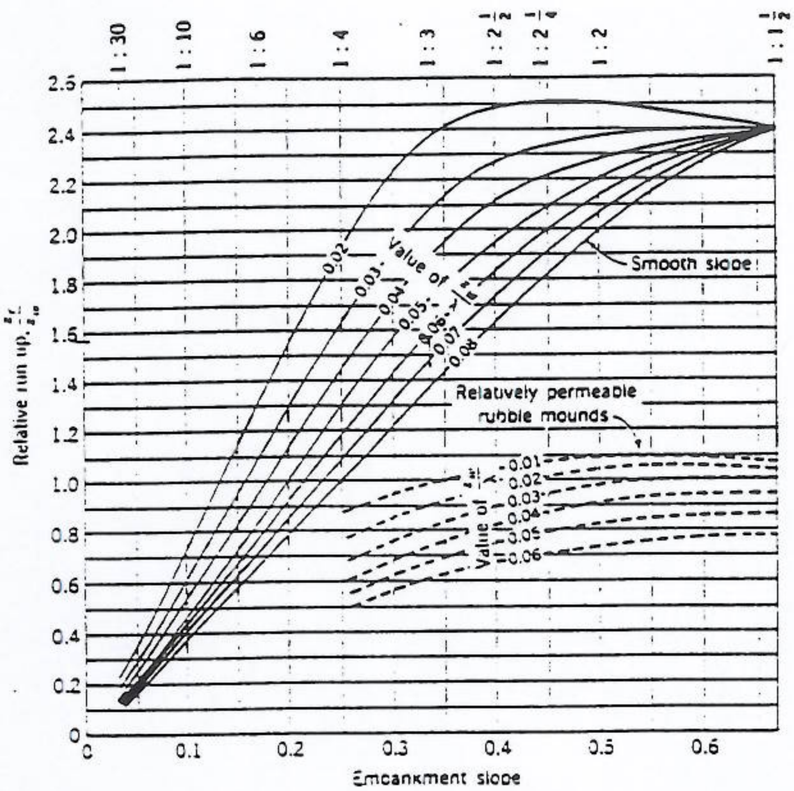

FIG. 7-13. Wave run-up ratios versus wave steepness and embankment slopes. *(From Saville, McClendon, and Cochran.)*

rubble mounds. Height of run-up z_r is shown as a ratio z_r/z_w and is dependent on the ratio of wave height to wavelength (wave steepness). Wavelength λ may be computed from

$$\lambda = 5.12 t_w^2 \tag{7-4}$$

where the wave period t_w is given by

$$t_w = 0.46 V_w^{0.44} F^{0.28} \tag{7-5}$$

TABLE 7-2. Per Cent of Waves Exceeding Various Wave Heights Greater than z_w
(After Saville, McClendon, and Cochran)

z'/z_w	1.67	1.40	1.27	1.12	1.07	1.02
Per cent of waves > z'	0.4	2	4	8	10	12

OTHER McGRAW-HILL HANDBOOKS OF INTEREST

HANDBOOK OF APPLIED HYDRAULICS

CALVIN VICTOR DAVIS *Editor-in-Chief*

Chief Technical Advisor, Harza Engineering Company, Chicago

KENNETH E. SORENSEN *Co-Editor*

Vice President, Harza Engineering Company, Chicago

THIRD EDITION

McGRAW-HILL BOOK COMPANY

New York St. Louis San Francisco London Sydney
Toronto Mexico Panama

tabular methods, etc.). Thus a variety of sequences of monthly and annual inflows may be considered, the sum total of which gives an evaluation of the probabilities involved.

There is an inherent psychological advantage to the stochastic approach, since the results must be expressed in terms of probabilities. This discourages a false sense of security that the design drought period will not be exceeded in severity—a feeling which can easily be obtained when the basis of design is the most critical period of record.

The stochastic approach is under rapid development. Although the basic philosophy, theories, and some procedural matters have been worked out, much remains to be done in the development of specific procedures before the approach can be considered to be fully operational. The classic work in this field was performed by Hurst,[1] followed by highly significant work by Langbein[2] and Fiering.[3]

To utilize the stochastic approach, it is necessary to develop several statistical parameters. These include the values of mean flow, measures of the variability of individual occurrences from the mean, and correlations between flows during previous periods and the flow during following periods. Although techniques for these analyses are undergoing rapid change, reference by the reader to the writings of the pioneer investigators referred to will provide basic background on the details of procedures that may be used.

After the statistical parameters are developed, they may be used to select random values of streamflow. This is the equivalent of "pulling historically observed streamflows from a hat," with proper constraints being applied to assure that unrealistic results will not be obtained. These constraints include such factors as the limitation on minimum flow that will be randomly selected (obviously it cannot be less than zero and usually it will be more) and the effect of the runoff from a previous period on the otherwise randomly selected runoff of a following period.

In using the stochastic approach it is necessary to decide on the number of years of record that should be generated and analyzed. While the number of years required to produce a result which has a certain probability of accuracy is undoubtedly subject to mathematical analysis, procedures have not yet been developed for this determination. Some investigators have arbitrarily utilized a 100-year generated record, but in some instances comparison of two separately generated 100-year periods has resulted in substantially different storage requirements.

Whatever the period of record that may be generated, it can be done most expeditiously and economically by use of a digital computer. Programs are available for this purpose, and these usually can be combined expeditiously with programs for analysis of the performance of the reservoir in meeting a variety of storage and delivery requirements.

The use of stochastic procedures, through development of a stochastic model, should not be interpreted as ignoring of historical data. Historical data are used to develop means, parameters of variability of flow, and relationships between successive flow periods. The only element of historical occurrences which is given small importance is the sequence of flows. This, however, is highly desirable since the historical sequence represents only one of many possibilities of sequence. The stochastic approach attempts, therefore, to put the historical sequence into proper perspective as to its probability of recurrence.

[1] Hurst, H. E., Long Term Storage Capacity of Reservoirs, Trans. ASCE, 1951, pp. 770–808.
[2] Langbein, W. B., Queuing Theory and Water Storage, Proc. ASCE, Paper 1811, October, 1958.
Langbein, W. B., and N. C. Matalas, Information Content of the Mean, J. Geophysical Res., August, 1963.
[3] Fiering, Myron B., Queuing Theory and Simulation in Reservoir Design, Trans. ASCE, 1962, vol. 1. pp. 1114–1144.

15. Application of Stochastic Approach. The use of the stochastic approach can be demonstrated by studies for a river in the Philippines. In that basin there were no runoff or precipitation data available for a large portion of the 1941–1949 period, with appreciable periods of record both before and after that time. Accordingly, the normal procedure for bridging of the gap in data by correlating runoff with precipitation was not possible.

The storage reservoir proposed for this basin is of the holdover type, with several years of drawdown between reservoir fillings. Because of this, it was essential that the sequence of runoffs for consecutive years be representative. The assumption that the record prior to 1941 would be continuous with the record starting in 1949 would be open to serious question. Accordingly, it was concluded that the best procedure would be to consider water supply on a stochastic basis.

In the stochastic analysis new sequences of historical flows were generated, utilizing the historical flow data as the basis. Normal distribution of the historical values about the mean was assumed in this analysis, except for certain controls that were placed on the sequence of monthly events. This control was developed by plotting successive monthly flows, one against the other, to develop serial correlations of successive monthly flows.

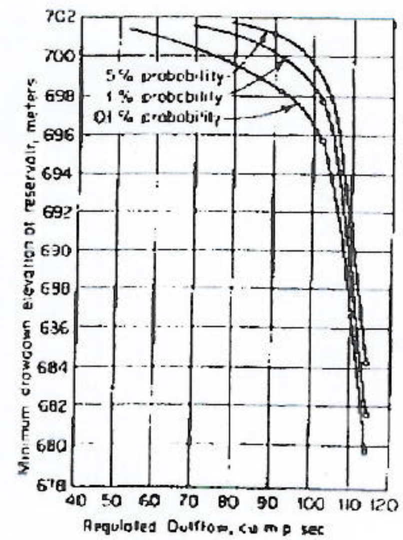

Fig. 8. Reservoir drawdown in critical period.

The generation of monthly streamflows, as well as operation studies necessary to estimate the dependable outflow, was by use of the digital computer. The drawdown was determined for four assumed controlled outflows by the digital computer, for several 100-year series of generated streamflow, and the resulting drawdowns were averaged. The results, expressed in terms of 0.1 percent, 1.0 percent, and 5.0 percent probabilities of recurrence, are shown in Fig. 8. These curves furnished a basis for selection of the probabilities of a shortage in water supply that could be tolerated in design of the reservoir.

RESERVOIR WAVE ACTION

16. Freeboard Allowances. The term "freeboard" is frequently used in different ways. As defined previously, freeboard must include consideration of the following:

1. Height of wind tide (referred to also as setup)
2. Height of waves in deep water generated by winds
3. Effect of wave run-up on sloping embankments on height of waves
4. Any additional margin of safety considered necessary

Final design decisions on freeboard allowances usually involve consideration of the type of dam, the situation governing the spillway design flood, and the effect of waves. This section is concerned only with wave action. An excellent article by Saville, McClendon, and Cochran[1] and a manual by the U.S. Corps of Engineers[2] form the basis of procedures given in this section for computing waves.

17. **Basic Assumptions.** A number of formulas have been developed for computation of heights of wind tide, waves, and run-up. Most of these involve use of wind velocity and fetch as basic parameters. While the different formulas will yield different results, the variation between formulas is frequently not so great as the variation possible in results that are due to assumptions as to wind velocity and fetch. Thus, the development of reasonable assumptions is of prime importance.

Wind. The magnitude of wind tide, wave height, and run-up will vary with the magnitude of wind velocity and the duration of that velocity. Thus, it is desirable to develop wind data on a duration basis, if possible. The proper combination of velocity and duration is not always subject to precise determination, although procedures are available in the computation of wave heights for determining the minimum required time to reach maximum wave heights. Frequently, maximum wave conditions will not result unless the duration is in the order of 1 hr. Therefore, in wind-tide calculations the maximum observed 60-min average wind is frequently taken as the first trial for design. This assumption then can be checked against the values of wind tides derived as described later.

Care should be taken to utilise only those wind conditions considered possible of occurrence at the same time or immediately following the meteorological conditions causing the pool level under consideration. For example, if the spillway design storm is not of the hurricane type, the winds used to compute freeboard allowances should not be of the hurricane type.

Fetch. Fetch length is the horizontal distance of open water surface over which the wind blows. The use of the greatest straight-line distance over open water in wave computations will result in computed wave heights that are too high, since the amount of adjoining open water having shorter but significant fetches influences the waves. Observations on artificial reservoirs have indicated that use of an "effective fetch" is more reliable. The effective fetch is computed by dividing the 45° angle on either side of the maximum fetch line into about 15 equal segments, multiplying the fetch length for each segment by the cosine of the angle of deviation from the maximum fetch line, and dividing the sum of the products by the sum of the cosines.

Wind velocities over water are generally higher than over land under comparable meteorological conditions, because of lesser roughness. The following values represent averages observed on artificial reservoirs:

Fetch, miles	0.5	1.0	2.0	3.0	4.0	5.0 (or over)
Wind ratio $\frac{\text{over water}}{\text{over land}}$	1.08	1.13	1.21	1.26	1.28	1.30

The maximum potential wind velocity may not always coincide in direction with the direction of maximum fetch. If observations of maximum winds of given directions are available, the use of the effective fetch length can be carried one step further, utilizing the appropriate design wind velocities with the fetches indicated.

18. **Wind Tide.** Wind tide, or "setup," is the piling up of water at the leeward end of an enclosed body of water, as a result of the horizontal stress on water exerted by the wind. The magnitude of wind tide can be expressed by the following modification of the Zuider Zee formula:

$$S = \frac{U^2F}{1{,}400D} \tag{3}$$

in which S is the wind tide (in feet) above still water, U is average wind velocity (in statute miles per hour) over the fetch distance F (in miles), and D is the average depth of water along the fetch line (in feet).

19. **Wave Height and Other Characteristics.** Wind-generated waves in a large body of water are not uniform in height. Successive waves will not be identical—each wave will be preceded and succeeded by a higher or lower wave. Data obtained from recordings of 45 storm periods at Fort Peck and Denison reservoirs have shown a very close comparison between the observed frequency distribution of wave heights on inland reservoirs with observed data on oceans. The following characteristics have been observed for the spectrum of waves observed at a given time and place:

% of total number of waves averaged to compute specific wave height H	Ratio of H to average wave height H_{av}	Ratio of H to significant wave height H_s	% of waves exceeding H
1	2.88	1.67	0.4
5	2.34	1.40	2
10	2.03	1.27	4
33⅓	1.60	1.00	13
50	1.42	0.89	20
100	1.00	0.62	46

The significant wave height H_s is defined as the average height of the highest one-third of all waves in a spectrum. As will be seen from the above tabulation, 13 percent of all waves can be expected to exceed H_s. These values would be reached at the end of a buildup period and give measures of the variations that can be expected in wave-height distributions. H_s may be computed by the set of curves in Fig. 9. Knowing the effective fetch and the wind velocity, the curve can be entered with these values to give the minimum time duration and value of H_s.

Once the value of H_s is computed, the occurrence frequency of a wave of any height can be computed from the preceding tabulation. The design height for waves H can be selected on the basis of consideration of frequency of winds of a given magnitude, duration of winds, and frequency of waves of given size. The finally selected design height must be a judgment value, involving consideration of the type of dam involved, as well.

20. **Wave Run-up on Slopes.** A wind-generated wave will be influenced when it runs up the slope of an embankment. The effect may be either to increase or to decrease the height of the wave in relation to the still-water surface, depending on wave characteristics and the slope, roughness, and permeability of the embankment. Therefore, the effect of run-up is usually combined with the actual wave height in computing allowances for wave action, into a single item designated as wave run-up height R.

In this sense R is the vertical distance between the maximum elevation obtained by a wave running up an embankment and the water elevation at the toe of the slope. The water elevation at the toe of the slope is the still-water elevation plus wind tide. Because of the relationship between wave height and run-up, it usually is convenient to compute run-up as a function of wave height.

[1] Saville, Thorndike J., Elmo W. McClendon, and Albert L. Cochran, Freeboard Allowances for Waves in Inland Reservoirs, *Trans. ASCE*, 1963, pt. IV, pp. 195–226.
[2] Waves in Inland Reservoirs, *Tech. Mem.* 132, Beach Erosion Board, U.S. Corps of Engineers, November, 1962.

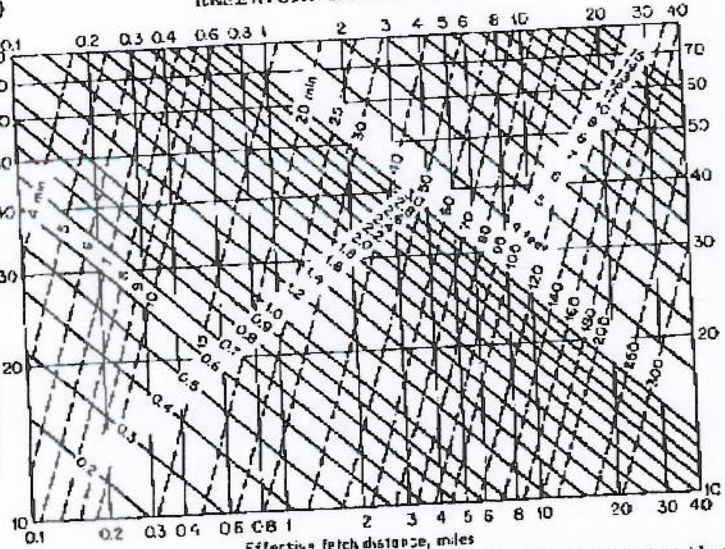

FIG. 9. Generalized correlations of significant wave heights H_s with related factors (deep-water conditions). Solid lines represent significant wave heights, in feet; dashed lines represent minimum wind duration, in minutes, required for generation of wave heights indicated for corresponding wind velocities and fetch distance. (*Beach Erosion Board, U.S. Corps of Engineers, Tech. Mem.* 132.)

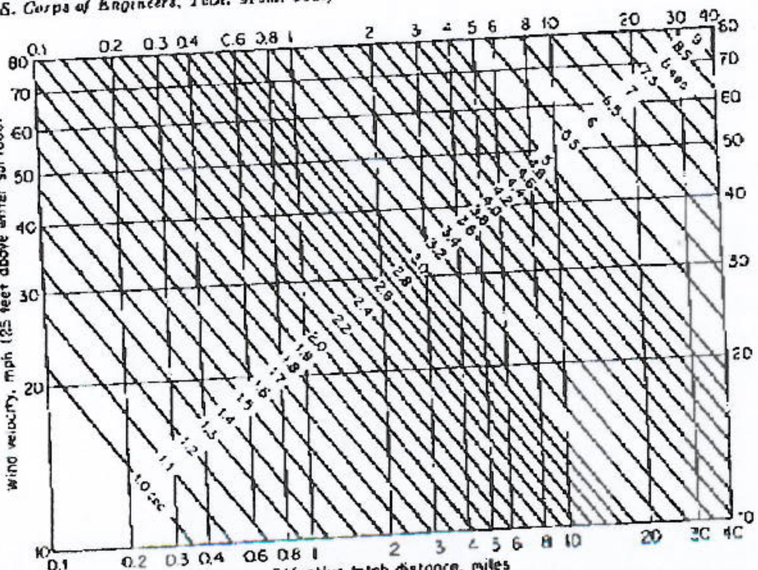

FIG. 10. Generalized relations between wave periods (T) and related factors (deep-water conditions). (*Beach Erosion Board, U.S. Corps of Engineers, Tech. Mem.* 132.)

The wave characteristics are represented by the wave steepness ratio H_o/L_o, where H_o = specific wave height and L_o = wave length, measured from crest to crest, in deep water. H_s may, for practical purposes in deep reservoirs, be taken as equal to H. L_o may be computed from the following formula:

$$L_o = 5.12T^2 \quad (4)$$

where T is the wave period, which may be determined from Fig. 10. This wave period is approximately the same for waves ranging between the significant wave H_s and

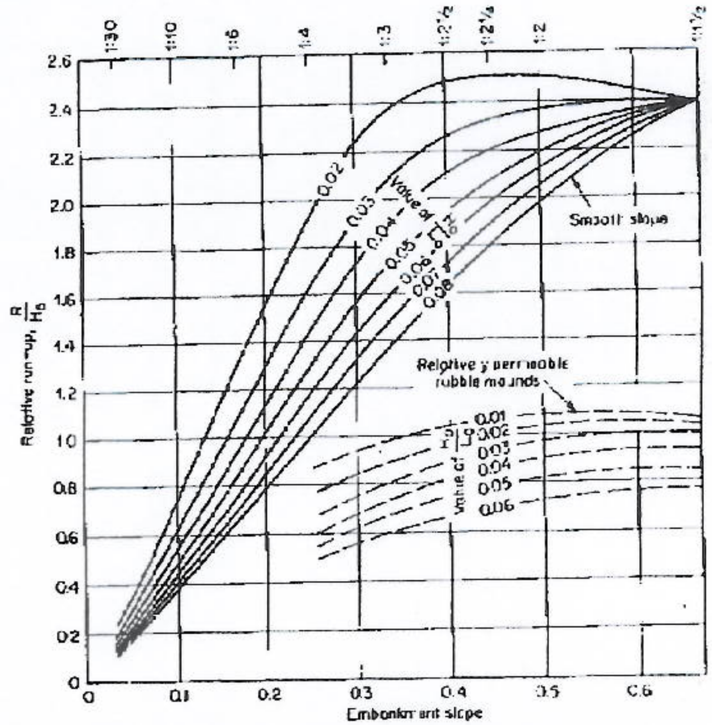

FIG. 11. Wave run-up ratios vs. wave steepness and embankment slopes. (*Trans. ASCE*, vol. 128, 317. 1963.)

the maximum wave H_{max}. Thus, in deep water the L_o determined for the wave steepness ratio can be used for any value of H between H_{max} and H_s. Deep-water conditions can be considered to be present when the depth at the toe of the slope is more than one-third of the calculated wave length.

Using the values of H_o and L_o, the effect of run-up on wave height may be computed from Fig. 11. Curves are shown for smooth slopes and for rubble mounds. Smooth slopes include surfaces such as well-graded earth embankments covered with sod and asphalt or concrete facing. Run-up on hand-placed riprap slopes approaches that computed for smooth slopes. Run-up on dumped riprap slopes can be considered to be about 50 percent of computed run-up on smooth slopes.