PB88-243787

Freeboard Determination and Management in Hazardous Waste Surface Impoundments

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Prepared for

Environmental Protection Agency, Cincinnati, OH

Aug 88

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA/600/2-88/015	2.	3. RECIPIENT'S ACCESSION NO. PB88 243787/AS
4. TITLE AND SUBTITLE Freeboard Detemination and Management in Hazardous Waste Surface Impoundments		5. REPORT DATE August 1988 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Sidney H. Johnson David C. Anderson		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS K. W. Brown and Associates 6A Graham Road College Station, Texas 77840		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. 68-03-1816
12. SPONSORING AGENCY NAME AND ADDRESS Hazardous Waste Engineering Research Laboratory Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final Report 1/87 14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES

Paul R. de Percin, Project Officer, 513/569-7797

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17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 102
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

EPA/600/2-88/015
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FREEBOARD DETERMINATION AND MANAGEMENT IN HAZARDOUS WASTE SURFACE IMPOUNDMENTS

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NOTICE

FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs, and regulations of the Environmental Protection Agency, the permitting and other responsibilities of State and local governments and the needs of both large and small businesses in handling their wastes responsibly and economically.

This report presents all of the information necessary to calculate freeboard requirements for hazardous waste surface impoundments. Each factor is discussed and incorporated into the mathmatical procedure for determining freeboard. This information will be useful to designers and permit reviewers for surface impoundments. For further information, please contact the Land Pollution Control Division of the Hazardous Waste Engineering Research Laboratory.

Thomas R. Hauser, Director
Hazardous Waste Engineering
Research Laboratory

ABSTRACT

A rule-of-thumb minimum freeboard requirement of two feet (60 cm) has been used in the past for hazardous waste surface impoundments. In many situations, however, this minimum value may not be sufficient to prevent overtopping. Consequently, a procedure was developed for calculating freeboard values in surface impoundments where the liquid depths are shallow and the fetches are short, as is typical in hazardous waste surface impoundments. The procedure takes into account all of the parameters which influence freeboard and presents the information in a format which can be used on a site-specific basis. Additional support information in the report includes an example calculation of freeboard requirement, site specific data obtained from research using a mass liquid balance, and a listing of the various types of liquid level detection equipment.

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SECTION 1

INTRODUCTION

Limited information has been supplied to owners, operators, and agency personnel concerning freeboard determination and liquid level control for surface impoundments. The rule-of-thumb which has generally been used in establishing freeboard, regardless of the size of the impoundment, has been to use two feet (60 cm) as a minimum requirement. In many situations this "minimum" value may not be sufficient to prevent overtopping during natural climatic events. This document presents a procedure for calculating freeboard which takes into account all of the factors which determine the behavior of a liquid in an impoundment.

PURPOSE AND SCOPE

The purpose of this document is to present all of the information necessary to calculate freeboard requirements on a site-specific basis. Section 3.0 presents the procedure for calculating freeboard and provides a discussion of the factors which influence freeboard, such as fetch, liquid depth, wave height and period, wind set-up, and wave run-up. Each factor is discussed and incorporated into the mathematical procedure for determining freeboard. Section 4.0 presents information on the two basic methods for detecting and maintaining a predetermined liquid level. Both methods, active and passive level control, are discussed along with suggested saftey margins.

Supplemental material included in the appendices is intended to augment the information presented in the body of the document. The appendices include: 1) a list of technical term definitions (Appendix A); 2) the procedure for calculating freeboard using a hypothetical surface impoundment design (Appendix B); 3) data collected from a field study on a liquid mass balance at a surface impoundment (Appendix C); and 4) a discussion of the various types of liquid level detection equipment which are currently available (Appendix D).

REGULATORY CONTEXT

Regulations listed in 40 CFR require owners and operators to maintain surface impoundment liquid levels in a manner which prevents overtopping. Regulations which address overtopping are found in CFR 264, 265, and 270. Part 264 addresses the operational standards for hazardous waste treatment, storage, and disposal facilities. Part 265 presents interim standards for these facilities and Part 270 discusses the current permitting requirements. Regulations, current through July 15, 1985, are presented below:

Section 264.221(f) states:

"a surface impoundment must be designed, constructed, maintained, and operated to prevent overtopping resulting from normal or abnormal operations; overfilling; wind and wave action; rainfall; run-on; malfunctions of level controllers, alarms, and other equipment; and human error."

Section 264.226(b)(1) states:

"while a surface impoundment is in operation, it must be inspected weekly and after storms to detect evidence of deterioration, malfunctions, and improper operation of overtopping control systems."

Section 265.222(a) and (b) state:

(a) "A surface impoundment must maintain enough freeboard to prevent any overtopping of the dike by overfilling, wave action, or a storm. Except as provided in paragraph (b) of this section, there must be at least 60 centimeters (two feet) freeboard."

(b) "A freeboard level less than 60 centimeters (two feet) may be maintained if the owner or operator obtains certification by a qualified engineer that alternate design features or operating plans will, to the best of his knowledge and opinion, prevent overtopping of the dike. The certification, along with a written identification of alternate design features or operating plans preventing overtopping, must be maintained at the facility."

Section 265.226(a)(1) states:

"The owner or operator must inspect the freeboard level at least once each operating day to ensure compliance with 265.222."

Additional information requirements are necessary for the Environmental Protection Agency (EPA) to determine compliance with the Part 264 standards, including:

Section 270.17(b)(2):

"Detailed plans and an engineering report describing how the surface impoundment is or will be designed, constructed, operated and maintained to meet the requirements of 264.221." This submission addresses the prevention of overtopping.

Sections 270.17(d):

"A description of how each surface impoundment, including the liner and cover systems and appurtenances for control of overtopping, will be inspected in order to meet the requirements of 264.226 (b). This information should be included in the inspection plan submitted under 270.14(b)(5)."

The EPA plans to update the above regulations. These new regulations should be consulted to determine if any changes have been made to those given above.

One intent of this document is to present a method for calculating freeboard which complies with regulations concerning overtopping as defined by 40 CFR 264, 265, and 270. These regulations have been formulated with the goal of eliminating, to the extent practical, the overtopping of liquids from surface impoundments. No single system, however, provides for absolute prevention of escape. Therefore, it is also the intent of this document to present information for use in designing a containment system which provides the maximum, practically achievable, level of freeboard safety during the operational life of the facility.

The goal of this document is to present performance guidelines and operating characteristics rather than specific numerical design values. However, a minimum freeboard of two feet is recommended. Information provided in this document is intended to offer the owner/operator flexibility in designing a suitable overtopping prevention system without dictating rigid design requirements.

Procedures set forth in this document for calculating minimum freeboard are based on current technology. Several design methods exist, however, which meet the requirements of 40 CFR 264.221(F). It is the responsibility of the owner/ operator to document the integrity of a the selected system as well as the ability of the system to meet the regulatory requirements.

SECTION 2

SUMMARY AND RECOMMENDATIONS

Procedures used in the past for calculating freeboard at surface impoundments were generally based on procedures and information developed by the Waterways Experiment Station (Corps of Engineers, 1984) and by Saville (1956). Much of this information is dated and does not take into account some of the variables which affect the ultimate freeboard value. To address these short-falls a new procedure was developed which addresses all of the factors which determine freeboard and incorporates them into an easy-to-follow format. Many of the coefficients used in the original work have been updated using new values derived from ongoing research (Herbich, 1986a). Unfortunately, updated information was not available for all parameters (e.g., roughness coefficient), therefore, values were either extrapolated or out-of-date published values were used. In spite of these limitations, the new procedure presented in this report represents the most up-to-date method for determining freeboard. The procedure takes into account all of the climatic factors and liquid characteristics which influence freeboard.

Based on the information gathered during preparation of the freeboard equation, two areas where information was lacking were noted. These included (1) the absence of roughness coefficients for smooth surfaces such as synthetic liner materials and (2) curves to determine wave run-up on these surfaces in impoundments where fetches are short and liquid depths are shallow. Therefore, it is recommended that a study be conducted to verify the roughness coefficient values established by Saville (1956) and to establish new coefficients for the synthetic materials commonly used to construct surface impoundment liners. Once these coefficients have been established it will be necessary to generate curves specifically designed to determine wave run-up in surface impoundments. One other area which may need attention in the future is determining the effects random waves have on run-up values. The equation presented in this document assumes all waves are monochromatic.

SECTION 3

FREEBOARD DETERMINATIONS

The overall design for freeboard allowance should be tailored to surface impoundments on a case by case basis to ensure that overtopping does not occur. To minimize the potential for overtopping, surface impoundments should include the following:

1. Passive outfalls from the surface impoundment, such as weirs or spillways which are insensitive to inflow should be incorporated into the design. In the event waste is released, these structures direct liquid waste to an on-site holding or treatment facility. Passive outfall structures are intended for use only in the event of an automated level control system malfunction, gross human error, or unforeseen catastrophic natural events;

2. If outfall structures are sensitive to inflow (i.e., where outfall rates must be increased to maintain freeboard as inflow increases) automatic control should be provided via signals from level sensing instruments. In these situations the automated system should include a high level alarm;

3. For surface impoundments receiving waste via inflow structures, design features should be incorporated which allow for flow of waste to the surface impoundment to be halted immediately in the event of overfilling or failure of any surface impoundment component. The flow of waste can be controlled by an automated level sensing system which, in the case of a system failure, can be operated manually;

4. Run-on control structures should be designed to divert the peak discharge from a 100 year/24-hour storm unless it can be shown that the surface impoundment is engineered to accept the additional volume without sacrificing minimum freeboard;

5. Freeboard should be defined as the minimum distance between the highest liquid level in the surface impoundment, where the highest liquid level includes changes in water elevation due to a 100 year/24-hour storm surge, and the liquid level which would result in the release of stored liquid from the surface

impoundment by overtopping (Figure 3.1). Freeboard allowances should be calculated for all surface impoundments using the maximum fetch (usually the diagonal measurement across the surface impoundment) and the maximum historically determined sustained wind speed to calculate wind set-up, wave height, and wave run-up. The minimum amount of freeboard maintained in the impoundment should be based on site specific calculations but should never be less than two feet (60 cm) except as provided for in 40 CFR 265.222(b). If the impoundment is equipped with a passive outfall such as a weir or spillway, freeboard should be measured from the highest allowable liquid level to the lowest discharge level of the passive outfall structure. When no passive outfalls are present, the freeboard should be the distance from the highest allowable liquid level to the top of the lowest elevation of the retaining structure. Freeboard should not be considered as storage capacity. Changes in liquid level due to a 100 year/24-hour storm should be engineered into the normal storage capacity of the surface impoundment; and

6. A weekly inspection schedule of all overtopping prevention equipment should be followed along with a daily inspection of freeboard. Additional inspections should be conducted following significant rainfall events to verify the integrity of the system and that minimum allowable freeboard has been maintained. Inspections should be made on level control sensors, alarms, and outfall structures. A written record should be maintained which documents the liquid levels, when inspections were conducted, who performed the inspections, and any observations made as to the integrity of the overtopping control systems. It is also recommended that a routine maintenance schedule be implemented for all overtopping control systems.

FACTORS WHICH AFFECT FREEBOARD

Determination of freeboard requires that several specific parameters be accurately measured. They include:

1. Fetch;
2. Liquid depth; and
3. Embankment slope.

Fetch, as used in this document, is defined as the maximum unobstructed distance across a free liquid surface over which wind can act. Typically, the longest fetch will be the diagonal measurement across the surface of the impoundment (Figure 3.2). Liquid depth, for the purpose of calculating freeboard, is the maximum possible depth of liquid (dm) in the surface impoundment (including storm surge). Embankment slopes of the surface impoundment should be clearly expressed for each sidewall of the impoundment (i.e., 3 horizontal to 1 vertical). If the embankment

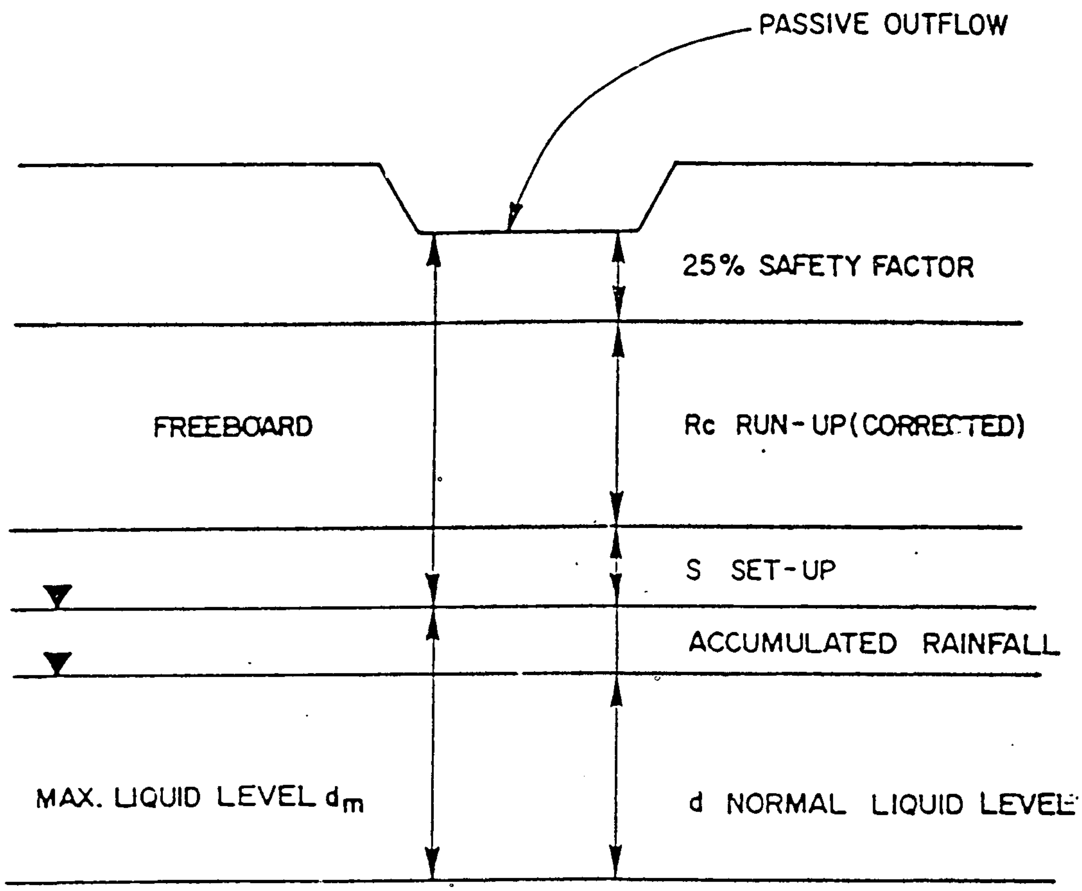


FIGURE 3-1. DEFINITION SKETCH FOR FREEBOARD.

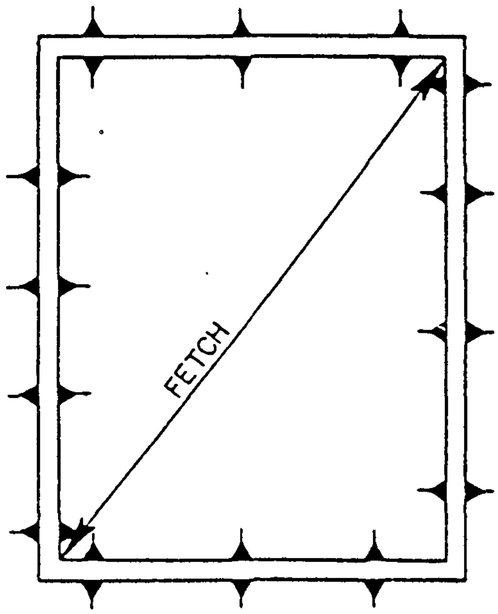


FIGURE 3-2. DEFINITION SKETCH FOR FETCH.

slopes vary, calculations should be performed using each slope value to determine which slope results in the greatest calculated freeboard.

Other parameters which affect freeboard include:

1. Wind speed;
2. Slope roughness;
3. Wind set-up;
4. Wave height and wave period; and
5. Wave run-up.

Wind speeds used in freeboard calculations should be based on local historical data for maximum sustained winds. In the absence of such data, it is suggested that a value of 75 mph be used for areas which are not subject to hurricanes and a value of 100 mph for areas which are hurricane prone. For the purpose of this document, "hurricane prone areas" are considered to be any area which is within 50 statute miles of a coastline subject to hurricanes.

A roughness factor for the interior face of the berm should be determined to establish freeboard requirements. Roughness factors will vary from a value of 1.0 for smooth synthetic liners to 0.45 for coarse surfaces such as rip-rap (Corps of Engineers, 1984). A rough surface will dissipate wave energy more quickly than a smooth slope, thereby resulting in a smaller value for wave run-up. Curves which relate slope roughness to other freeboard parameters are an acceptable means for determining roughness effects (assuming a roughness coefficient of 1.0 is appropriate in most situations.) Using a roughness coefficient of 1.0 means that no correction is required for any of the wave forecasting equations included in this document.

Wind set-up is an important parameter to be considered when determining freeboard requirements since it has the net effect of raising the water level on the downwind side of the impoundment (Figure 3.3). As wind acts on the liquid surface, the liquid is "pushed" to the far side of the impoundment, causing a slight gradient on the water surface.

Wave height and wave length will determine the type of waves generated within a given impoundment. The relationship between these two parameters will define whether shallow or deep waves are generated and if the wave will break. Under most circumstances waves will be shallow and non-breaking, therefore, all of the equations included in this document are for use in situations where waves do not break.

The final and most important parameter, wave run-up, is dependent on many of the preceding parameters. Run-up is defined as the vertical height to which water rises above the still water level on a sloped embankment (Figure 3.4). Final freeboard determinations must be based on this value.

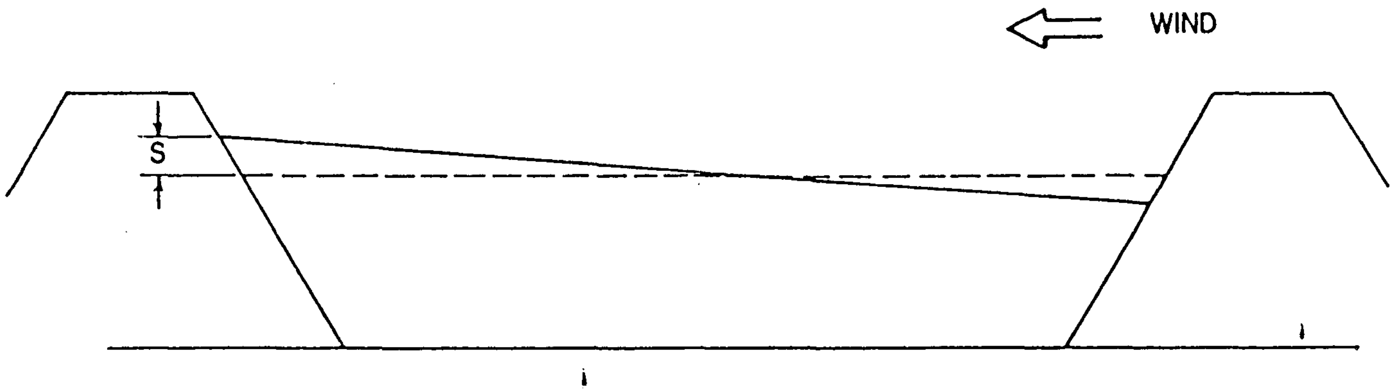


FIGURE. 3-3. DEFINITION SKETCH FOR WIND SET-UP(S).

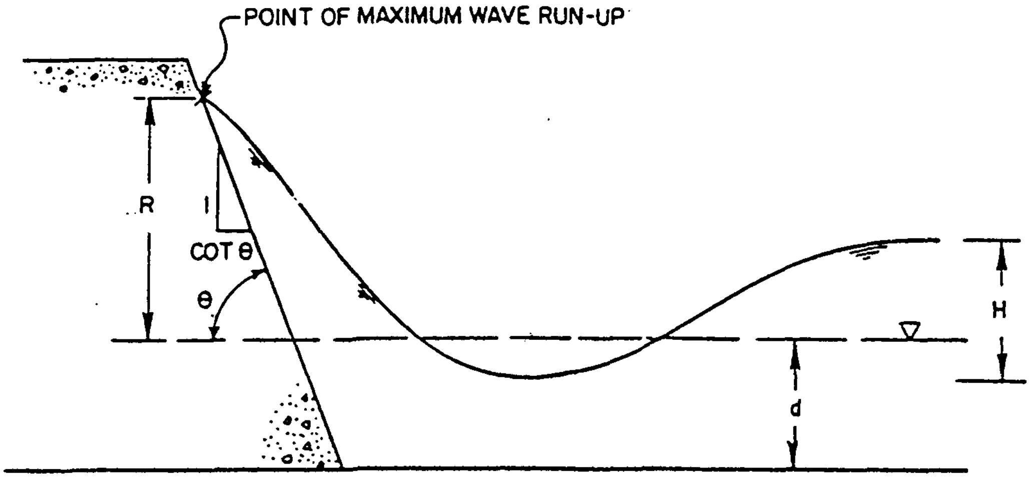


FIGURE 3-4. DEFINITION SKETCH FOR WAVE RUN-UP

Values for these variables must be accurately defined to determine freeboard requirements for surface impoundments. Consequently, owners/operators should use site-specific data in calculating all parameters. In instances where site-specific data is unavailable, conservative estimates of these values should be incorporated into calculations of minimum freeboard.

CALCULATING FREEBOARD

The following procedure was developed to allow estimation of freeboard in conditions where short fetches and shallow liquid depths predominate. For the purpose of this document, short fetches will be considered any distance less than 5,280 feet (1,600 meters) and shallow depths will be defined as values less than 30 feet (9 meters). These values were selected because more than 90% of hazardous waste surface impoundments fit into these definitions.

The first step in calculating freeboard is to accurately measure the physical dimensions of the surface impoundment. These measurements include length and width to determine the maximum fetch as well as the maximum liquid depth possible in the surface impoundment. Sidewall slopes should be measured or determined from as-built engineering drawings. Having defined these values it will be necessary to collect local information on such weather conditions as rainfall and wind speed.

Based on this information, the following calculations for wave height, wave period, wind set-up, and wave run-up can be used to determine freeboard requirements. In the following equations, U is wind speed (ft/sec) and U_a is a wind stress factor (ft/sec). The relationship between these two values is: $U_a = 0.589\ U^{1.23}$.

Wave Height:

$$\frac{gH}{U_a^2} = 0.283 \tanh\left[0.53\left(\frac{gd_m}{U_a^2}\right)^{0.75}\right] \tanh\left\{\frac{0.00565\left(\frac{gF}{U_a^2}\right)^{0.5}}{\tanh\left[0.53\left(\frac{gd_m}{U_a^2}\right)^{0.75}\right]}\right\}$$

Where:

U_a = Wind Stress Factor (ft/sec)
H = Wave Height for Shallow Water (ft)
F = Fetch (ft)
d_m = Maximum Depth of Impounded Liquid (ft)
g = Acceleration of Gravity (32.16 ft/sec^2)

Wave Period:

$$\frac{gT}{U_a} = 7.54 \tanh\left[0.833\left(\frac{gd_m}{U_a^2}\right)^{0.375}\right] \tanh\left\{\frac{0.0379\left(\frac{gF}{U_a^2}\right)^{0.333}}{\tanh\left[0.833\left(\frac{gd_m}{U_a^2}\right)^{0.375}\right]}\right\}$$

Where:

U_a = Wind Stress Factor (ft/sec)
T = Wave Period (sec)
F = Fetch (ft)
d_m = Maximum Depth of Impounded Liquid (ft)
g = Acceleration of Gravity (32.16 ft/sec2)

Wind Set-Up:

$$\frac{S}{F} = \frac{AU_a^2}{gd_m} + \left(\frac{B(U_a - U_o)^2}{gd_m}\right) \times \left(\frac{d_m}{F}\right)^{0.5}$$

given:

$$U_o = 21.0\left(\frac{g\rho_l\nu_l}{\rho_a}\right)^{0.33}$$

Where:

A = 3.30 x 10-6
B = 2.08 x 10-4
U_a = Wind Stress Factor (ft/sec)
U_o = Wind Speed; Formula Characteristic Velocity (ft/sec)
F = Fetch (ft)
S = Set-up (ft)
ρ_l = Density of Liquid Impounded (lbs/ft^3)
ρ_a = Density of Air (0.075 lbs/ft^3 @ 20°C and 760 mm Hg)
ν_l = Kinematic Viscosity of Liquid (ft^2/sec)
d_m = Maximum Depth of Impounded Liquid (ft)
g = Acceleration of Gravity (32.16 ft/sec^2)

Wave Run-Up:

Unlike the previous parameter determinations, wave run-up is an involved procedure of calculating and adjusting formula variables. The procedure which will be followed is adapted from Herbich, 1985b. Much of the data which support the various types of freeboard calculations can be found in the Shore Protection Manual (U. S. Army Corps of Engineers, 1984) and Saville (1956). Steps in determining wave run-up are as follows:

- Calculate deep water wave length (L_o).

  $L_o = \left(\frac{g}{2}\right) T2 = 5.12\ T2$ (in feet)

- Calculate d_m/L_o.

- Locate the value of d/L_o (d_m/L_o) in Table 4-1 and read corresponding values for d/L and H/H_o. If d/L_o (d_m/L_o) is greater than or equal to 1.000, then $H = H/H_o'$.

- Calculate the value of Ho' from H/H_o'.

- Calculate $\frac{H_o'}{L_o}$ and $\frac{H_o'}{gT^2}$

- Obtain $\frac{R}{H_o'}$ using H_o'/gT^2 from Figure 3-5.

Where:

d_m = Maximum Liquid Depth (ft)
H_o = Deep Water Wave Height (ft)
H = Shallow Water Wave Height (ft)
T = Wave Period (sec)
L_o = Deep Water Wave Length (ft)
L = Shallow Water Wave Length (ft)
R = Run-up (ft)
g = Acceleration of Gravity (32.16 ft/sec^2)

Once a value for run-up (R) has been established it will be necessary to correct this value using a coefficient of 1.67 (R_c = 1.67 R; where R_c is the corrected run-up value). The preceding wave forecasting calculations are based on averages for the highest wave which would occur out of three waves generated ($H_{1/3}$). It is advisable to use a more conservative approach in handling hazardous wastes. One such conservative approach would be to use R values which account for the highest wave that would occur out of 100 waves generated ($H_{1/100}$). The coefficient used to find R_c is based on work by Longuet-Higgins and Stewart (1964) and can also be found in Kinsman (1965).

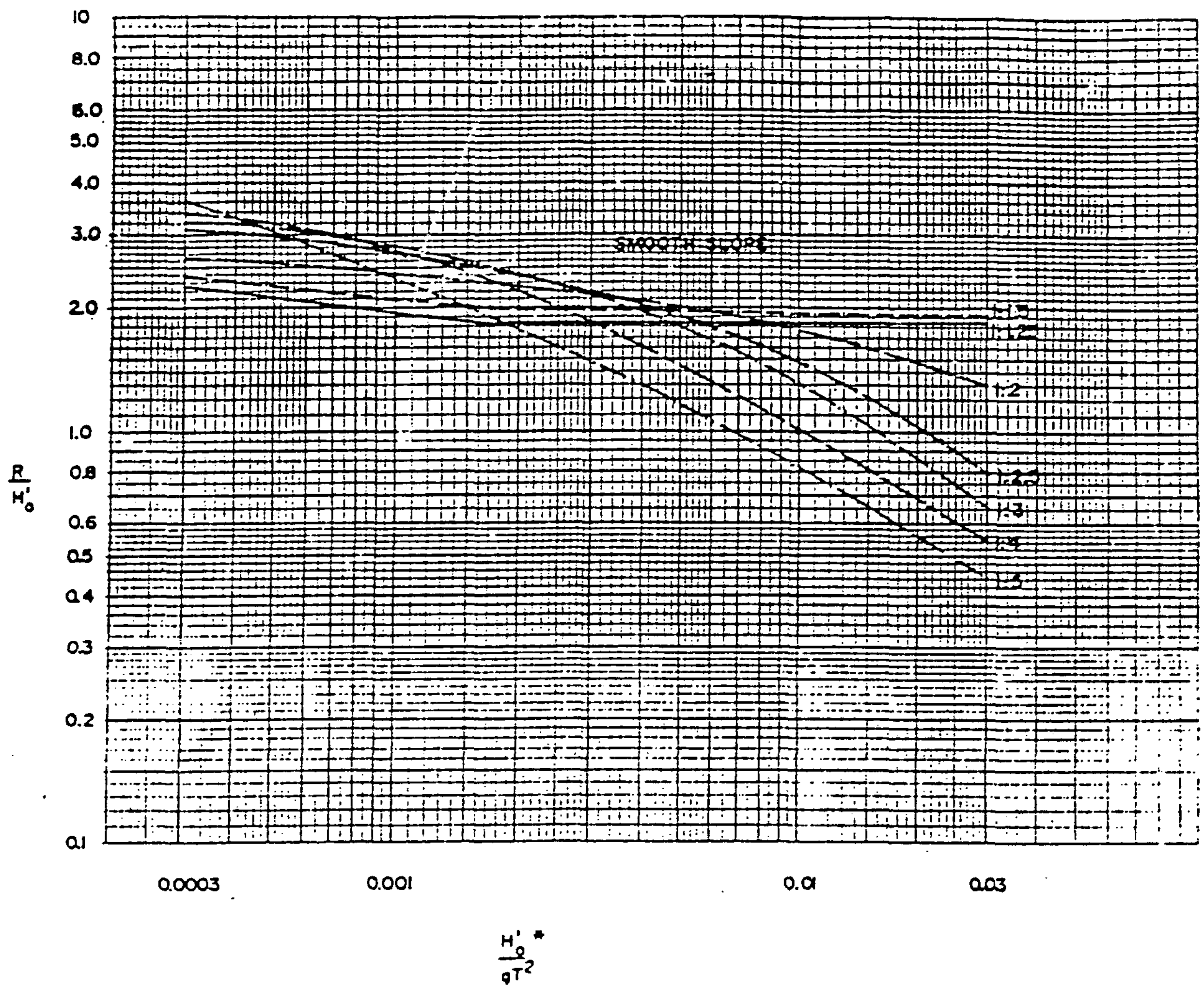


FIGURE 3-5. COMPARISON OF WAVE RUN-UP ON SMOOTH SLOPES (DATA FOR $d/H_0' > 3.0$; SAVILLE, 1956).

* VALUES GREATER THAN 0.015 HAVE BEEN EXTRAPOLATED.

FREEBOARD ALLOWANCE

The minimum freeboard which should be observed is the sum of the calculated values for set-up (S) and corrected wave run-up (R_c) from the preceding equations. Changes in liquid elevations due to the 100 year/ 24-hour storm surge should never be included in the freeboard allowance.

Wave forecasting is not an exact science and these equations assume ideal conditions using monochromatic waves and in some cases extrapolated values for short fetches and shallow water depths. For surface impoundments that handle hazardous wastes, it is advisable to add a safety factor of 25% to the freeboard allowance and to never allow the freeboard to be less than two feet, except as provided for in 40 CFR 265.222(b). The 25% correction should apply to the sum of the corrected run-up (R_c) and set-up (S). Therefore, the total freeboard allowance (f) should be expressed as follows:

$f = 1.25\,(R_c + S)$ if it is less than 2 feet, use the recommended 2 foot minimum.

Where:

f = Freeboard (ft)
R_c = Wave Run-up, corrected (ft)
S = Wind Set-up (ft)

SECTION 4

FREEBOARD MANAGEMENT

Maintaining liquid level can be viewed as a two phase problem. First, there is the need to monitor and control the liquid level at or below the established value. To accomplish this, passive and active (electrically operated) level control systems may be employed. Regardless of the type of system selected, it is advisable to identify a specific system prior to finalizing impoundment design so needed modifications can be incorporated into the design and construction plan for the impoundment.

The second phase in the design of a SI should include a passive level control device such as a weir, spillway, or outflow pipe. The purpose of the passive structure is to prevent catastrophic failure of the impoundment dike in the event that the active level control system fails or an unforeseen natural event occurs. Passive level control devices should be designed for use only in emergency situations, not as part of normal facility operations unless the passive structure is part of a flow through treatment process. In an emergency, the passive level control should direct the liquid to a tank or another surface impoundment.

ACTIVE LEVEL CONTROL

Once freeboard allowances have been determined it will be necessary to implement some type of system which monitors liquid level. Numerous systems have been used in the past, most of which require human input to function properly (e.g., staff gauges). By and large, these types of systems are incapable of sensing the liquid level and therefore can not be used to control freeboard directly. Bearing this in mind, it is advisable to consider the use of an automated (active) liquid level sensing system. Active level sensing systems offer several advantages including continuous level monitoring which can be used to automatically maintain freeboard, the ability to translate level readings into a volume for waste inventory when interfaced with a controlling unit, and the inherent fail-safe feature of many systems which virtually eliminates human error.

Active control of the liquid level in a surface impoundment is typically comprised of four phases. The overall objective of the integrated four phase system is to control the liquid level in such a manner that a predetermined maximum level (and minimum level if necessary) is not exceeded. To this end, each of the four phases must be linked together in a logical controlling sequence. The four phases include: 1) the primary element, 2) the measuring element, 3) the controlling element, and 4) the final control element (Figure 4-1).

The primary element, Phase I (e.g., float, probe, ultrasonic beam, etc.) detects or senses changes in the liquid level. The measuring element, Phase II, receives the signal from the primary element and measures the amount the liquid level has deviated from a set point or from the last measurement. The controlling element, Phase III, uses data from the measuring element to activate or alter power to the final control element. The controlling element is generally a computer, such as a digital or analog type, where the liquid level limits are set and the decision is made as to the amount of liquid to be allowed to inflow or outflow. The final control element, Phase IV, is typically a pump or valve which actually influences the amount of liquid flowing into or out of the impoundment.

The primary and measuring elements are generally combined into a single unit referred to as the level detection system. A wide variety of level detection equipment is available, and generally is the most variable of the elements in total level control system (Table 4-1). The level detection, monitoring and control system described above may be designed to operate as a totally automated system. That is, the system can detect, monitor and control the liquid level with little contact from technicians other than routine maintenance and calibration.

As stated, controlling liquid level in a surface impoundment is a process which includes several phases. Figure 4-2 gives a visual display of the level monitoring and control procedure, including inflow to the impoundment and outflow from the impoundment. To aid in system selection a discussion of the various types of level detecting devices is offered in Appendix D and can also be found in greater detail in Shiver et al. (1985).

PASSIVE LEVEL CONTROL

The easiest types of systems which can be used to control liquid level are passive outfall structures such as a spillways, weirs, or pipes. Many of these types of structures can be engineered to meter the rate of flow, and as a whole are typically insensitive to inflow, meaning that as the rate of inflow to the impoundment increases the rate of flow through the outfall structure increases without recalibration or manual adjustment. The use of these types of outfall or outlet works are common in flow- through processes (e.g., settling basins or polishing ponds). In these situations the liquid outfall is directed from the impoundment to the next step in the treatment process via the outlet structure, and therefore does not constitute an uncontrolled release.

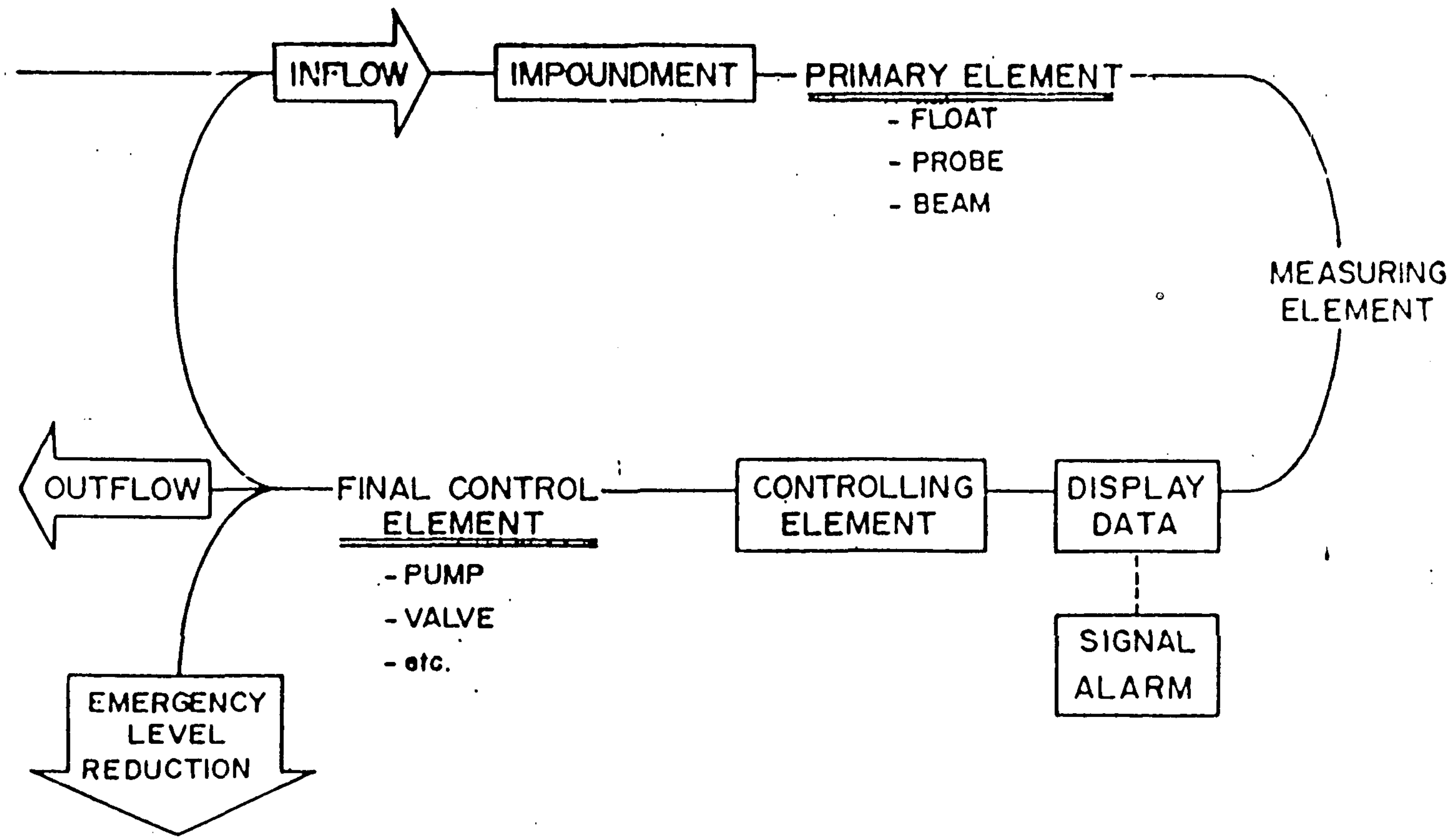


FIGURE 4-1. SCHEMATIC OF LIQUID LEVEL CONTROL.

Table 4-1. Liquid Level Detection Systems.

System	Application	Principle of Operation	Advantages	Limitations
Capacitance	Non-corrosive wastes; corrosive w/mod	Measurement of stored electrical charge	Fail safe operation, easy operation	Based on liquid dielectric constant, affected by coating
Conductivity	Non-corrosive, conductive mat'ls	Completion of circuit through the liquid	Easy installation, inexpensive	Primarily point level only, requires conductive liquids
Diaphragm	Non-corrosive and corrosive wastes	Measurement of pressure increase due to liquid head	Diaphragm does not contact liquid, unaffected by minor surface agitation	Poor sensitivity to small level change, based on liquid density
Differential Pressure	Non-corrosive and corrosive w/mod	Measurement of pressure difference between liquid bottom and atmospheric	Sensor does not contact waste	Based on liquid density
Displacers	Non-corrosive wastes, corrosive w/mod, non-coating wastes	Measurement of force of displaced float, converted to depth	Used for continuous level monitoring, can detect interface	Must be calibrated for each liquid, based on density
Floats	Non-corrosive and corrosive waste w/ mod	Float remains in contact w/liquid surface to measure fluctuation	Continuous level monitoring, inexpensive	Constant contact w/ waste, affected by surface agitation
Impedance Probe	Non-corrosive, coating wastes, corrosive w/mod	Same as capacitance w/ shielding to overcome coating affects	Not as affected by coating wastes, no moving parts	Dependent on dielectric constant, relatively expensive
Level Gauge	Non-corrosive and corrosive wastes	Basically visual level monitoring and recording from gauge	Direct level measurement, inexpensive	Requires technician, difficult to incorporate into secondary controls
Infrared Sensors	Non-corrosive, non-coating and some corrosive wastes	Detection of reflected or refracted light	Very sensitive, safe in flammable liquids	Fouled by coating, expensive, basically point level sensing
Resistant Tapes	Non-corrosive and corrosive wastes	Contact of two elements due to pressure of rising liquid	Continuous level monitoring, not usually affected by coatings	Density sensitive
Thermal Sensors	Non-corrosive, non-coating liquids	Detect temperature between probe and liquid or vapor	Continuous level monitoring, accuracy	Density sensitive, affected by coating
Ultrasonic	Non-corrosive and corrosive	Reflection of ultrasonic beam to liquid surface	Does not contact liquid, continuous level monitoring	Inaccuracies due to surface turbulence or foam

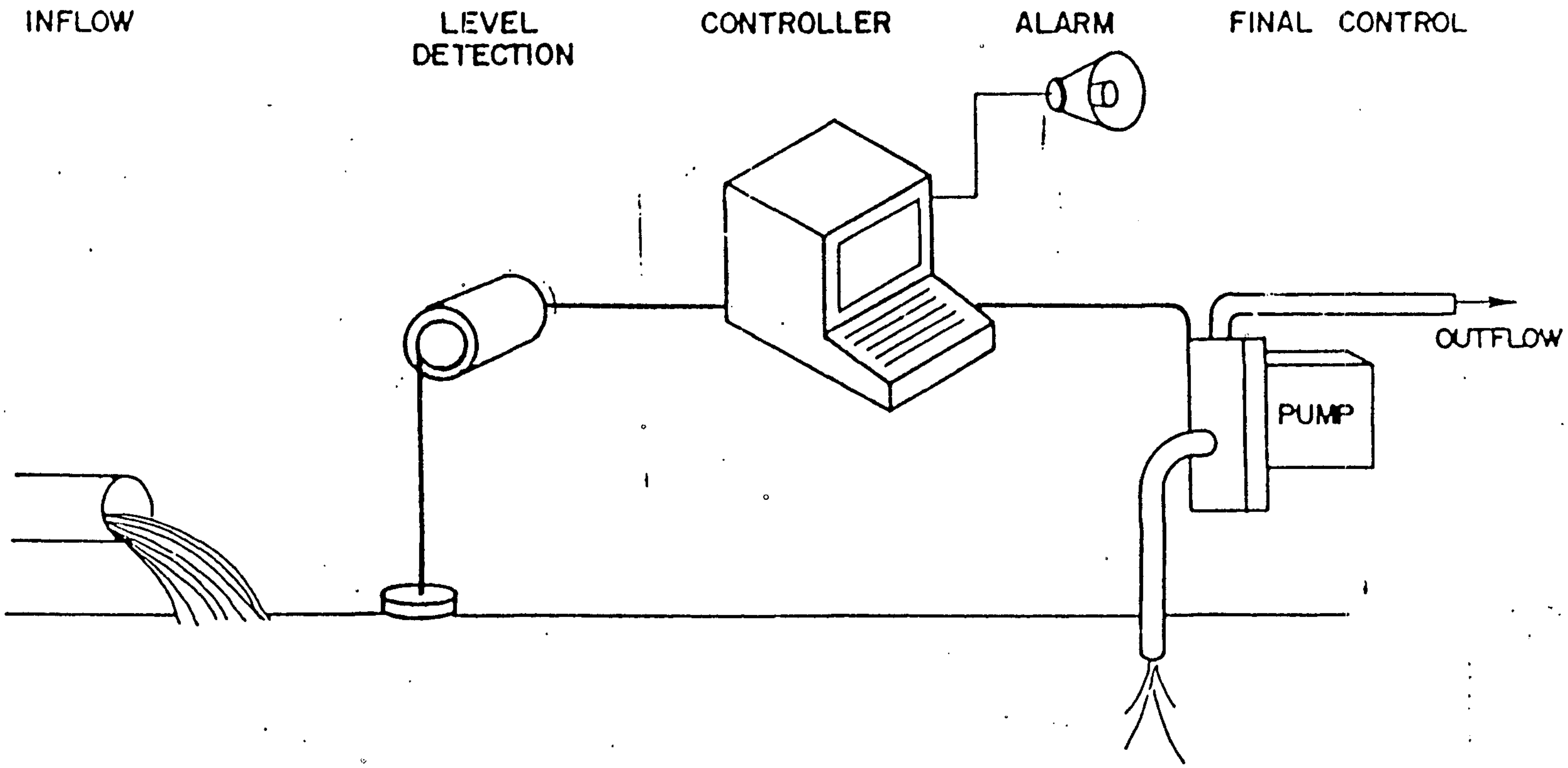


FIGURE 4-2. SCHEMATIC OF LIQUID LEVEL MANAGEMENT SYSTEM.

Surface impoundments used for liquid storage or disposal are notably different than the flow-through process discussed above. In these types of surface impoundments, passive outfall structures should only be used to control liquid level in order to prevent overtopping in the event active level control systems fail. Therefore, in these situations the passive outfall structure should be viewed as a backup "safety valve" to the active level control system with the sole purpose of preventing overtopping which could cause catastrophic dike failure. Since most of these types of impoundments are not designed to return liquid to a treatment process, any flow of liquid through the passive structure would constitute an uncontrolled release.

Regardless of the situation where the passive outfall is to be used, there are general design specifications which should be observed. First, the type of outlet to be used must be identified. Spillways or weirs will represent the most desirable option for most situations. These types of structures can be easily sized to meet the outflow needs of the impoundment, are relatively inexpensive, and when used with a stage recorder can be used to meter the flow of liquid. Pipe or conduit outlet works are not generally recommended because they require placing a hole through the liner and berm of the impoundment. If a good seal is not realized around the conduit, seepage of liquid may occur which ultimately could lead to piping of the soil, thereby resulting in failure of the berm. If pipes are to be used it is recommended that metal pipes be avoided. Since many types of waste are corrosive and most soils are inherently co rosive to some extent, metal pipes will have a finite life expectancy. If metal pipes are used, consideration should be given to coating the pipes with a resistant material and/or providing cathodic protection.

Designing an outlet for a surface impoundment will require defining the relationship between inflow and outflow volumes. Unlike the more conventional applications for passive outlet structures such as dams at lakes, the inflow to a surface impoundment can easily be determined from operational processes and climatic data which define the maximum operating level. Having identified the maximum volume which can be added to the impoundment, the outflow structure can be designed to handle this volume. The following weir equation (Linsley and Franzini, 1979) defines the discharge volume over a spillway:

$$Q = C_w L h^{3/2}$$

where:
- Q = Discharge
- C_w = discharge coefficient
- L = Length of the crest
- h = head on the spillway (vertical distance from the crest of the spillway to the reservoir level).

The discharge coefficient will vary depending on the design of the spillway and amount of head. Figure 4-3 illustrates coefficients for a standard crest shaped spillway.

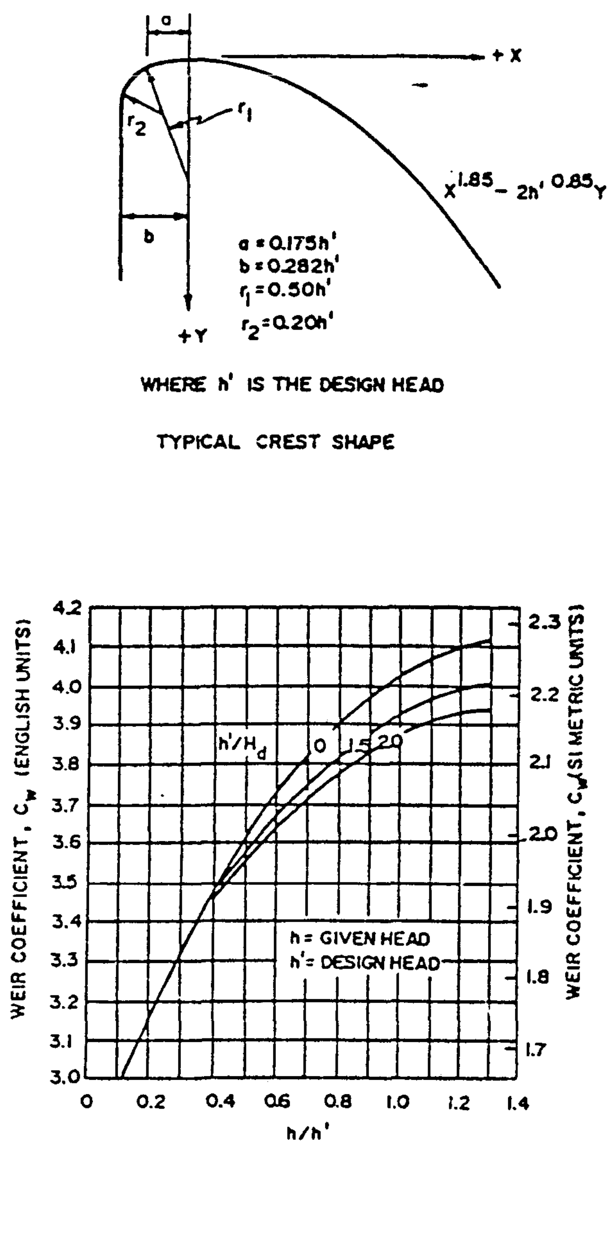


FIGURE 4-3. DISCHARGE OF AN OVERFLOW SPILLWAY (LINSLEY AND FRANZINI, 1979).

If the use of a weir is proposed, several different designs can be selected including the V-notch, rectangular, and the Cipolletti types (Figure 4-4). A related structure which may be considered is a flume. The specific goal of these structures is to provide a passive outfall which allows the flow of liquid through the structure to be metered. Flow calculations for each are listed below.

From Considine (1974):

V-Notch Weir:	60° Notch	$Q = 1.46\ H^{5/2}$	(see Figure 4-4a)
	90° Notch	$Q = 2.52\ H^{2.47}$	
Rectangular Weir:		$Q = 3.33(L - 0.2H)^{3/2}$	(see Figure 4-4b)
Cipolletti Weir:		$Q = 3.367\ LH^{3/2}$	(see Figure 4-4c)

From Linsley and Franzini (1979):

Parshall Flume: $Q = 4Bh_a^{1.522B^{0.026}}$ (see Figure 4-4d).

The final category of passive outfalls includes pipes, nozzles, and conduits. As previously mentioned, these types of outfalls are not generally recommended for use at surface impoundments. Problems which may arise when these structures are used include liner leakage or metal pipe corrosion which may lead to soil erosion and dike failure, seepage of waste through the liner, and the limited ability of the structure to adjust to increases in liquid flow volume. Determination of flow through pipes can be calculated as follows:

Darcy-Weisbach Formula for fairly smooth pipe (Hicks, 1972):

$$h_F = \frac{0.38\ L\ V^{1.86}}{1000\ D^{1.25}}$$ solve for V and use $Q = VA$

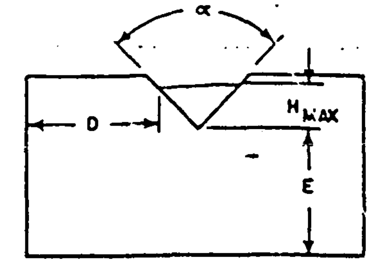
where: h_F = friction head (ft) — D = diameter of pipe (ft)
L = length of pipe (ft) — Q = flow volume (ft)
V = velocity of liquid (ft/sec) — A = area of pipe (ft^2)

Manning Formula for full flow through round pipes (Hicks, 1972):

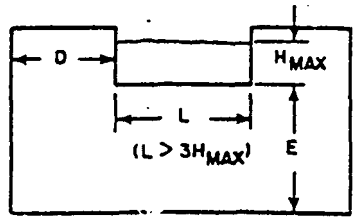
$$D = \left(\frac{2.159\ Q\ n}{S^{1/2}}\right)^{3/8}$$

where: D = diameter of pipe (ft) — Q = flow volume (cfs)
n = roughness coefficient — S = gradient of pipe (hL/L)

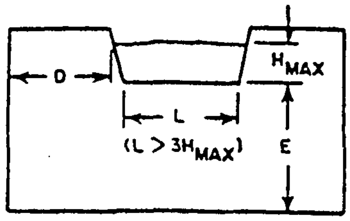
(A) V-NOTCH WEIR



(B) RECTANGULAR WEIR



(C) CIPOLLETTI WEIR



(D) PARSHALL FLUME

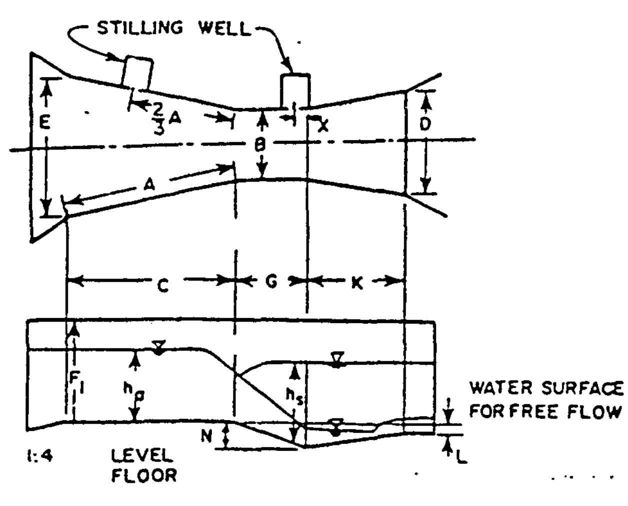


FIGURE 4-4. OPEN CHANNEL FLOW.

e.g.: n = 0.009 for smooth brass of glass
n = 0.013 for concrete
n = 0.014 for average drain tile
n = 0.021 for corrugated iron

The above procedures are only a brief overview of the techniques available to passively control liquid levels. If further information is required or there is a specific need for an unusual situation it is advised that the listed references be consulted.

QUALITY ASSURANCE

It is advisable to implement a quality assurance program to ensure that the freeboard control system selected operates according to the manufacturer's design specifications. Since a specific freeboard control system (or any components of the system) are not recommended, no specific quality assurance program will be recommended. Rather, the approach taken is to present general procedures which should be observed to ensure that all level control devices are installed correctly and operate properly.

All surface impoundments should use accurately calibrated equipment to measure both inflow and outflow. Automated inflow and outflow structures, when used, should have the capacity to be operated manually in the event automatic controls fail to regulate the flow of liquid. All surface impoundments should be equipped with fail safe high level alarms. It is also advisable to install level sensing probes which interface with inflow and outflow structures.

Regardless of the type of overtopping system selected, the owner/operator should maintain a written record documenting the procedures used to install and calibrate all equipment and structures associated with liquid level control. In addition, documentation should include verification that the type of system selected is compatible with the type of waste impounded. Once installed, the system should be tested to verify that it is fail safe. These tests should be designed to test the integrity of the entire system, including deliberate actions to verify operation of all fail safe aspects of the system.

After the system has been verified as operating properly, the calibration and testing procedures should be incorporated into a program for routine maintenance of all liquid level control system components. Personnel assigned the responsibility for daily inspection and routine maintenance of the liquid level control system should be familiar with operation of all system components and should have a written protocol detailing the lines of authority, the procedures and schedule for testing the equipment (including calibration specifications), reporting requirements, and all associated contingency plans.

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10. Shiver, R., S. Johnson and J. D. Zabcik. 1985. Methods for Detecting Liquid Level and Maintaining Minimum Freeboard at Hazardous Waste Surface Impoundments. Draft Technical Report Prepared by K. W. Brown and Associates, Inc. Contract No. 68-03-1816, Assignment 6.

APPENDIX A -

DEFINITION OF TECHNICAL TERMS

DEFINITION OF TECHNICAL TERMS

Fetch - The maximum unobstructed distance across a free liquid surface over which wind can act (typically the diagonal measurement across an impoundment).

Freeboard - The distance between the highest calculated liquid level in a surface impoundment and the liquid level which would result in the release of stored liquid from the impoundment.

Monochromatic - Waves which all have the same wave length (as used in this document).

Overtopping - Flow of stored liquid over the top of the dike or levee.

Outfall - A structure, e.g., weir or spillway, that diverts and controls the liquid flow.

Outrun - Flow of liquid out of the impoundment other than by overtopping.

Roughness Factor - A measure of smoothness of the berm inside wall which varies from 1.0 for synthetic plastic liners to 0.45 for stone rip-rap.

Run-On - A flow of liquid into the surface impoundment due to rain and the local topography.

Wind Set-Up - The extent to which a gradient on the water surface is caused by wind pushing the liquid to the far side of an impoundment.

WAVE ~~Wind~~ Run-Up - The vertical height to which liquid rises above a still liquid level on a sloped embankment due to waves.

APPENDIX B

CALCULATING FREEBOARD REQUIREMENTS

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B.1 INTRODUCTION

The following procedure was designed to estimate freeboard in impoundments where short fetches and shallow liquid depths predominate. For the purpose of this document, short fetches will be considered any distance less than 5,280 feet (1,600 meters) and shallow depths will be defined as values less than 30 feet (9 meters).

In the following equations, U is wind speed (ft/sec) and U_a is a wind stress factor (ft/sec). The relationship between these two values is: $U_a = 0.589\ U^{1.23}$.

B.2 WAVE HEIGHT

$$\frac{gH}{U_a^2} = 0.283 \tanh\left[0.53\left(\frac{gd_m}{U_a^2}\right)^{0.75}\right] \tanh\left\{\frac{0.00565\left(\frac{gF}{U_a^2}\right)^{0.5}}{\tanh\left[0.53\left(\frac{gd_m}{U_a^2}\right)^{0.75}\right]}\right\}$$

Where:

U_a = Wind Stress Factor (ft/sec)
H = Wave Height for Shallow Water (ft)
F = Fetch (ft)
d_m = Maximum Depth of Impounded Liquid (ft)
g = Acceleration of Gravity (32.16 ft/sec^2)

B.3 WAVE PERIOD

$$\frac{gT}{U_a} = 7.54 \tanh\left[0.833\left(\frac{gd_m}{U_a^2}\right)^{0.375}\right] \tanh\left\{\frac{0.0379\left(\frac{gF}{U_a^2}\right)^{0.333}}{\tanh\left[0.833\left(\frac{gd_m}{U_a^2}\right)^{0.375}\right]}\right\}$$

Where:

U_a = Wind Stress Factor (ft/sec)
T = Wave Period (sec)
F = Fetch (ft)
d_m = Maximum Depth of Impounded Liquid (ft)
g = Acceleration of Gravity (32.16 ft/sec^2)

B.4 WIND SET-UP

$$\frac{S}{F} = \frac{AU_a^2}{gd_m} + \left(\frac{B(U_a-U_o)^2}{gd_m}\right) x \left(\frac{d_m}{F}\right)^{0.5}$$

given:

$$U_o = 21.0 \left(\frac{g\rho_l\nu_l}{\rho_a}\right)^{0.33}$$

Where:

A = 3.30×10^{-6}
B = 2.08×10^{-4}
U_a = Wind Stress Factor (ft/sec)
U_o = Wind Speed; Formula·Characteristic Velocity (ft/sec)
F = Fetch (ft)
S = Set-up (ft)
$_l$ = Density of Liquid Impounded (lbs/ft^3)
$_a$ = Density of Air (0.075 lbs/ft^3 @ 20°C and 760 mm Hg)
$_l$ = Kinematic Viscosity of Liquid (ft^2/sec)
d_m = Maximum Depth of Impounded Liquid (ft)
g = Acceleration of Gravity (32.16 ft/sec^2)

B.5 WAVE RUN-UP

Unlike the previous parameter determinations, wave run-up is an involved procedure involving calculating and adjusting formula variables. The procedure which will be followed is adapted from Herbich (1986). Much of the data which support the various types of freeboard calculations presented here can be found in the Shore Protection Manual (U. S. Army Corps of Engineers, 1984) and Saville (1956). Steps in determining wave run-up are as follows:

- Calculate deep water wave length (L_o).

  $L_o = (\frac{g}{2}) T^2 = 5.12\ T^2$ (in feet)

- Calculate d_m/L_o.
- Locate the value of d/L_o (d_m/L_o) in the Appendix and read corresponding values for d/L and H/H_o. If d/L_o (d_m/L_o) is greater than or equal to 1.000, then $H = H/H_o'$.
- Calculate the value of H_o' from H/H_o'.
- Calculate $\frac{H_o'}{L_o}$ and $\frac{H_o'}{gT^2}$
- Obtain $\frac{R}{H_o'}$ using H_o'/gT^2, as depicted in Figure B-1.

Where:

d_m = Liquid Depth (ft)
H_o' = Deep Water Wave Height (ft)
H = Shallow Water Wave Height (ft)
T = Wave Period (sec)
L_o = Deep Water Wave Length (ft)
L = Shallow Water Wave Length (ft)
R = Run-up (ft)
g = Acceleration of Gravity (32.16 ft/sec^2)

The preceding wave forecasting calculations are based on averages for the highest one-third of waves generated ($H_{1/3}$). For example, if waves generated during a one hour storm have wave periods of two seconds, it is anticipated that a total of 1800 waves will be generated, 600 of which will equal or exceed the run-up value calculated using $H_{1/3}$. Obviously a more conservative approach should be used when dealing with hazardous wastes. One approach is to use a correction factor which converts the $H_{1/3}$ to $H_{1/100}$ values (highest average wave generated out of 100 waves). To make the run-up correction, a coefficient of 1.67 is used ($R_c = 1.67\ R$; where R_c is the corrected run-up value). The coefficient used to find R_c is based on work by Longuet-Higgins and Stewart (1964) and can also be found in Kinsman (1965).

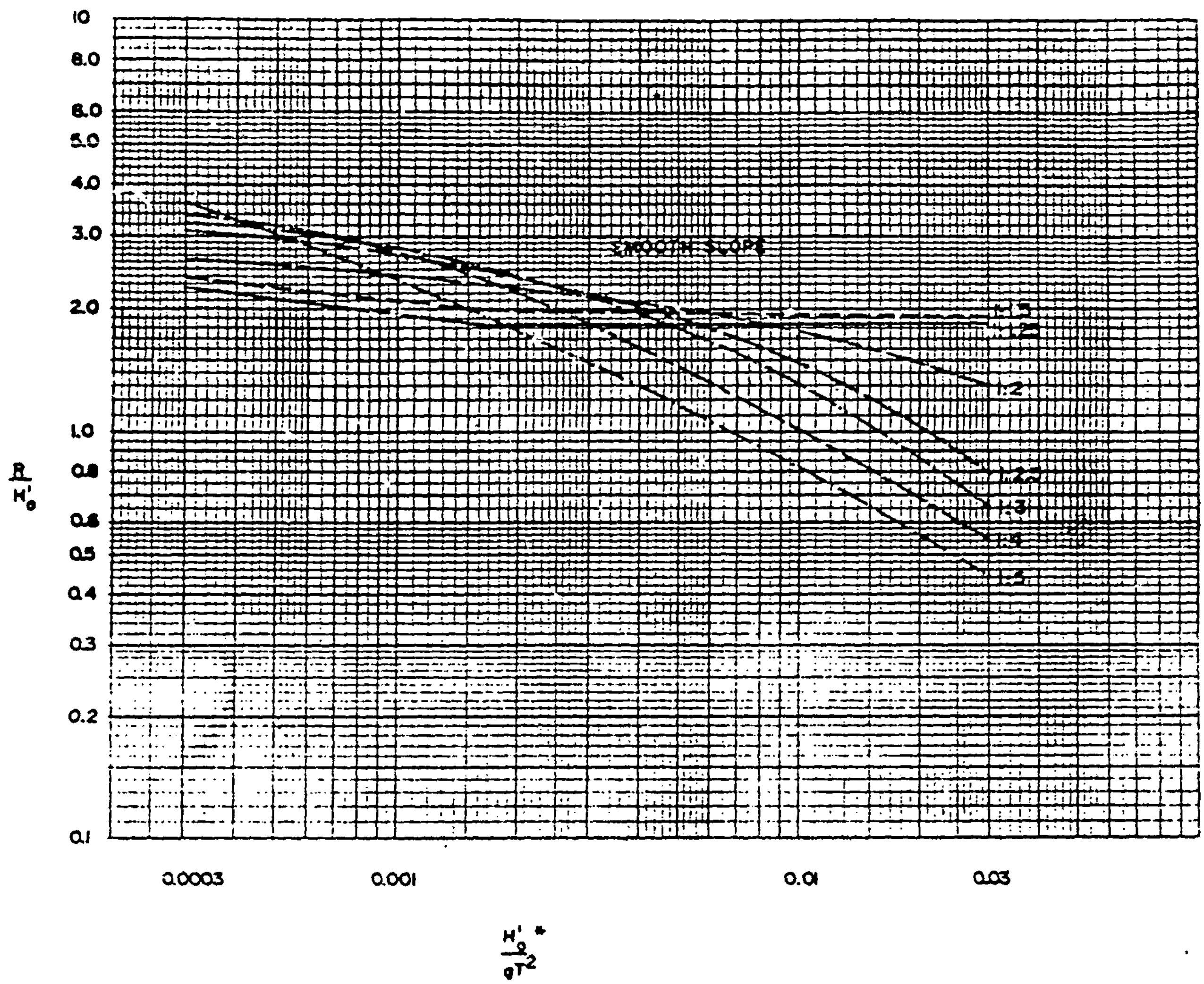

FIGURE B-1. COMPARISON OF WAVE RUN-UP ON SMOOTH SLOPES (DATA FOR $d/H'_0 > 3.0$; SAVILLE, 1956).

* VALUES GREATER THAN 0.015 HAVE BEEN EXTRAPOLATED.

B.6 FREEBOARD ALLOWANCE

The minimum freeboard which should be observed is the sum of the calculated values for set-up (S) and corrected wave run-up (R_c), from the preceding equations. Changes in liquid elevations due to the 100 year/24 hour storm surge are not included in this freeboard allowance calculation (Figure B-2).

Wave forecasting is not an exact science since it assumes ideal conditions using monochromatic waves, and in some cases extrapolated values for short fetches and shallow water depths. It may be advisable to include a margin of safety (e.g. 25%) in the final freeboard allowance. If a correction factor is used, it should apply to the sum of the corrected run-up (R_c) and set-up (S).

Example:

Given a SI has a maximum fetch of 300 feet, a liquid depth of 10 feet, sidewall slopes of 3 horizontal to 1 vertical, and is located in an area not subject to hurricanes, calculate the minimum freeboard requirement.

F = 300 feet
d_m = 10 feet
Slope = 3:1
U = 75 mph (wind speed)

First it is necessary to convert U and Ua into units of ft/sec.

$$U = \frac{75 \text{ miles}}{\text{hour}} \times \frac{1 \text{ hour}}{3{,}600 \text{ sec}} \times \frac{5{,}280 \text{ ft}}{1 \text{ mile}} = 110 \text{ ft/sec}$$

$$Ua = 0.589\ (110 \text{ ft/sec})^{1.23} = 191 \text{ ft/sec}$$

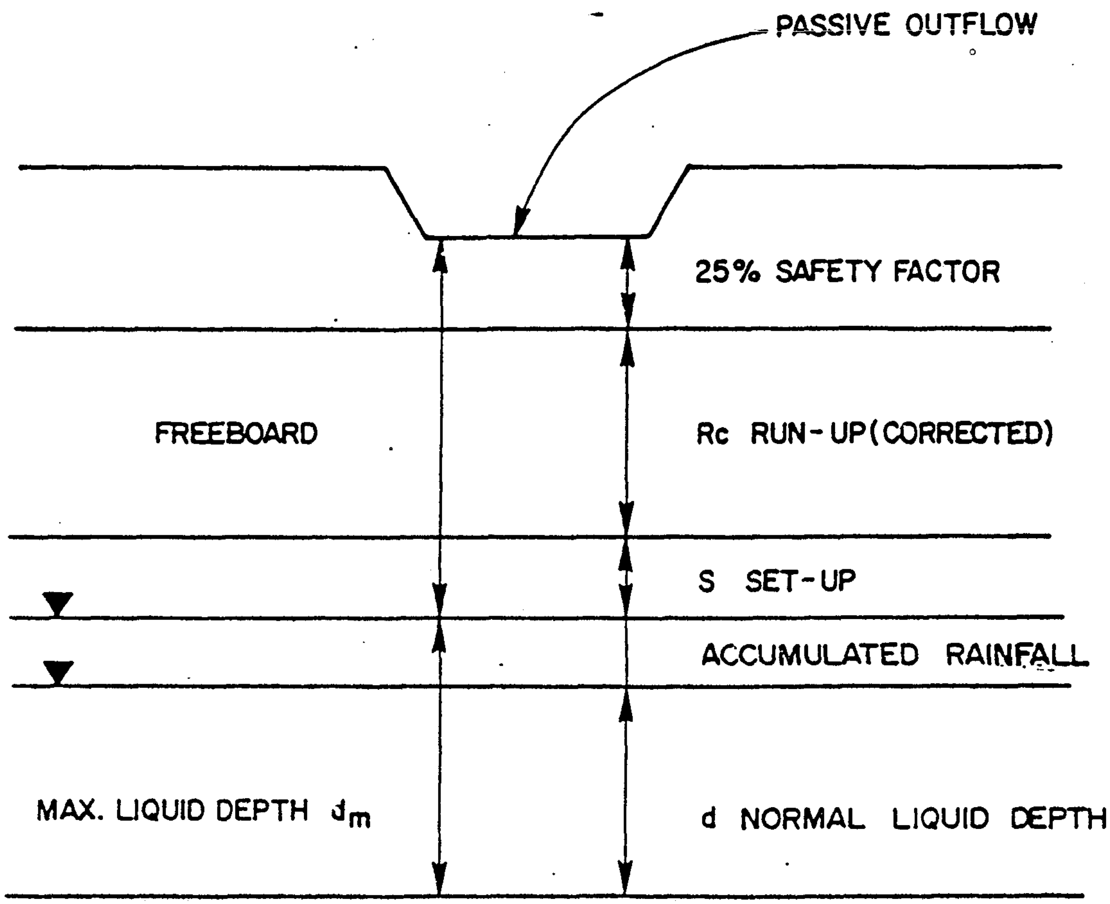

FIGURE B-2. DEFINITION SKETCH FOR FREEBOARD.

B.6.1 WAVE HEIGHT

Substituting given values into the wave height equation yields:

$$\frac{(32.16\ \text{ft/sec}^2)\ H}{(191\ \text{ft/sec})^2} = 0.283\ \tanh\left[0.53\left(\frac{(32.16\ \text{ft/sec}^2)(10\ \text{ft})}{(191\ \text{ft/sec})^2}\right)^{0.75}\right] \times$$

$$\tanh\left\{\frac{0.00565\left(\frac{(32.16\ \text{ft/sec}^2)(300\ \text{ft})}{(191\ \text{ft/sec})^2}\right)^{0.5}}{\tanh\left[0.53\left(\frac{(32.16\ \text{ft/sec}^2)(10\ \text{ft})}{(191\ \text{ft/sec})^2}\right)^{0.75}\right]}\right\}$$

H = 0.92 ft

B.6.2 WAVE PERIOD

Solving the wave period equation gives:

$$\frac{(32.16\ \text{ft/sec}^2)\ T}{(191\ \text{ft/sec})} = 7.54\ \tanh\left[0.833\left(\frac{(32.16\ \text{ft/sec}^2)(10\ \text{ft})}{(191\ \text{ft/sec})^2}\right)^{0.375}\right] \times$$

$$\tanh\left\{\frac{0.0379\left[\frac{(32.16\ \text{ft/sec}^2)(300\ \text{ft})}{(191\ \text{ft/sec})^2}\right]^{0.333}}{\tanh\left[0.833\left(\frac{(32.16\ \text{ft/sec}^2)(10\ \text{ft})}{(191\ \text{ft/sec})^2}\right)\right]^{0.375}}\right\}$$

T = 1.08 sec.

B.6.3 WAVE SET-UP

Using the wave set-up equation solve for S given the liquid has a kinematic viscosity of 0.22 H^2/sec a density of 53.06 lbs/ft^3 and the density of air is 0.075 lbs/ft^3.

$$U_o = 21.0 \left(\frac{(32.16\ ft/sec^2)(53.06\ lbs/ft^3)(0.22\ ft^2/sec)}{(0.075\ lbs/ft^3)} \right)^{0.33}$$

U_o = 359 ft/sec

$$\frac{S}{(300\ ft)} = \frac{(3.3 \times 10^{-6})(191\ ft/sec)^2}{(32.16\ ft/sec^2)(10\ ft)} + \frac{2.08 \times 10^{-4}\ (191\ ft/sec - 359\ ft/sec)^2}{(32.16\ ft/sec^2)(10\ ft)} \times \left(\frac{10\ ft}{300\ ft}\right)^{0.5}$$

S = 1.11 ft

B.6.4 WAVE RUN-UP

To calculate wave run-up, use the following procedure:

Find the deep water wave length

$L_o = 5.12\ ft/sec^2\ T^2$

$= (5.12\ ft/sec^2)(1.08\ sec)^2$

$= 5.97$ ft

Find the ratio of dm/L_o = 10 ft/5.97 ft = 1.68

Since the ratio of $dm/L_o > 1.0$, there is no need to correct the H value derived earlier ($H_o' = 0.92$ ft).

Find H_o'/L_o and H_o'/gT^2

H_o'/L_o = 0.92 ft/5.97 ft = 0.15

$H_o'/gT^2 = 0.92\ ft/(32.16\ ft/sec^2)(1.08\ sec)^2 = 0.025$

From Figure B-1 find R/H_o' using H_o'/gT^2 for a 1:3 slope.

$R/H_o' = 0.75$

$R = 0.75\ (0.92\ \text{ft}) = 0.69\ \text{ft}$

Solve for the corrected run-up value:

$R_c = 1.67\ (0.69\ \text{ft}) = 1.15\ \text{ft}$

B.6.5 FREEBOARD ALLOWANCE

Using the preceding calculations, find the freeboard allowance (f).

$f = 1.25\ (R_c + S)$

$= 1.25\ (1.15\ \text{ft} + 1.11\ \text{ft})$

$= 2.83\ \text{ft}$

For this impoundment, 2.83 feet represents the minimum amount of freeboard which should be maintained.

B.7 REFERENCES

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APPENDIX C

WATER BALANCE

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C.1 INTRODUCTION

The primary purpose of this study was to investigate the use of the water balance method to quantify seepage from surface impoundments. Water balance parameters that were examined included surface inflow and outflow, precipitation, evaporation, change in storage, and seepage. A field study was conducted using selected methods and instruments. A discussion of what is known about surface impoundments nd what would be gained by conducting water balances on these facilities follows.

A recent study by the EPA (1983) determined that there were over 180,000 surface impoundments in the United States. These impoundments are used to treat, store, and dispose industrial, municipal, agricultural, mining, and oil production wastes. Approximately 28,000 of the impoundments contained industrial wastes such as those covered under EPA hazardous waste regulations.

Over 50 percent of the industrial impoundments are located over unsaturated zones that are either very thin or very permeable. This would provide very little potential for attenuating hazardous waste constituents before these pollutants reach groundwater. Over 80 percent of the industrial impoundments are located over thick and very permeable aquifers. This would allow rapid movement of contaminant plumes once these pollutants reach groundwater. Over 40 percent of the industrial sites are located in areas with thin or permeable unsaturated zones and overlie high flow rate aquifers containing water that is currently in use or of high quality. Only two percent of the sites are located more than one mile from high quality groundwater. Finally, only seven percent of the sites are located in hydrogeologic settings that provide a high degree of groundwater protection (EPA, 1983). Only 30 percent of the industrial sites are lined.

Groundwater contamination has already been documented at hundreds of the 28,000 industrial surface impoundments. Over 30 percent of these documented cases of contamination are from impoundments associated with the industrial category of "Chemical and Allied Products". The cause of groundwater contamination in the vast majority of cases (86.3 percent) was listed as seepage or liner failure (EPA, 1983). For the failed sites that were lined, the primary reason for failure was loss of liner integrity.

Contamination was detected most often (45 percent) by the discovery of adversely affected water supplies. About 30 percent of the cases were detected by monitoring wells, but many of the impoundments had monitoring wells installed only after seepage was noted. In less than five percent of the cases, a water balance was used to detect seepage prior to obvious groundwater contamination. It is highly probable that had a water balance been maintained on the other surface impoundments, excessive seepage would have been detected before groundwater contamination had occurred.

Water balances have long been used to quantify leakage from large lakes and drinking water reservoirs. The degree of sophistication used to determine the water balance of a body of water can vary from extremely simple to extremely complex (Mather, 1978). While the most complex methods may require highly skilled personnel, the simplest methods may be extremely inaccurate. The approach taken in this water balance study was to aim for the highest level of accuracy possible using methods that could be routinely used by unskilled personnel.

Conclusions and recommendations derived from the water balance study are given in Sections C.2 and C.3, respectively. Materials and methods are presented in Section C.4, and Section C.5 offers interpretations of the data.

C.2 CONCLUSIONS

There is a need for a method to quantify seepage from surface impoundments. Such a method should be easy to operate, accurate in field conditions, and sensitive enough to detect small rates of seepage. In addition, the method should both be relatively inexpensive and generate unambiguous data to facilitate its interpretation by the user and regulatory communities. The water balance method described in this report can satisfy all of the above objectives.

When performing a water balance to quantify seepage from a surface impoundment, the primary concerns are accuracy and sensitivity. There should be a high degree of accuracy in the measurement of the individual parameters. The water balance should also sense the smallest practical rate seepage in order to serve as an early warning of impending groundwater contamination. In most cases, the one water balance parameter that cannot be measured is seepage. The water balance equation is, therefore, used to solve for this unknown parameter. The sensitivity and level of accuracy for the measurements of the other water balance parameters will determine the magnitude of seepage that can be detected. Methods and instruments used to perform the water balance will define the sensitivity and accuracy of the system.

Two of the methods that can be used to solve the water balance equation are calculating volume changes and calculating level changes. By calculating volume of the impoundment and monitoring all volumetric inputs and outputs, it is possible to define volumetric seepage. This procedure has neither the accuracy nor sensitivity necessary because it uses calculations based on an impoundment volume equation which can introduce large errors. Therefore, in most situations, this approach should not be used. The second method is based on using a level recorder to directly measure level changes to within 1 mm. Both short term and continuous inputs and outputs can be documented extremely accurately as water level changes. This procedure eliminates many of the sources of error inherent in the volumetric water balance calculations. The largest source of error in calculating level changes results from the need to distinguish between seepage and evaporation losses. Since both are output parameters which are not short-term events, the accuracy with which evaporation is measured will define what rate of seepage can be detected. Therefore, the method used to monitor evaporation losses becomes the largest remaining source of error.

Many methods exist for monitoring evaporation losses from surface impoundments. These range from extremely complicated energy budget methods to the simple evaporation pan method. It is generally felt that the more complicated methods offer a higher degree of accuracy and that accuracy is compromised by using the simplest approach. The intensity with which evaporation must be monitored for an energy budget method and the skill level necessary to use the required instruments renders the method too complex for routine use. In contrast, the use of evaporation pans requires little skill and the devices can readily be used for routine monitoring. Many types of evaporation pans are available and each has advantages and disadvantages. Generally, evaporation from pans that are buried and contain larger volumes of water will more accurately approximate the evaporation from the impoundment.

Relating the evaporation rate of the pan to that of the impoundment is the most critical step in the water balance method. Correlation of the evaporation values is done by means of a pan coefficient. Pan coefficients vary depending on the type and size of pan used. The value of pan coefficients are usually based on annual data and caution should be used when evaluating evaporation for a shorter period of time.

It appears that the level monitoring method is the most accurate and most sensitive method for this type of study as long as the following conditions exist:

1) The level recording device is as accurate as possible and has a sensitivity of 1 mm.

2) Inputs and outputs are short-term events of known duration.

3) The pan coefficient used is based on annual data.

If these conditions are met, the water level of an impoundment can be monitored with the degree of accuracy necessary to quantify very low seepage rates.

C.3 RECOMMENDATIONS

A standard method should be established for the routine monitoring of the water balance in hazardous waste surface impoundments. During this study, a method was developed that can adequately monitor the water balance of most surface impoundment configurations. The level monitoring method can be a very accurate and easy to use technique which is capable of quantifying small seepage rates. Two areas where uncertainty exists include 1) the correlation of evaporation values between the pan and impoundment and 2) the accuracy of volume calculations in a water balance equation. Further research should be conducted to:

1) establish evaporation pan coefficients as they apply to various wastes over long time periods;

2) derive volume formulas within known error values;

3) determine the limitations of the level method in areas where freezing temperatures and solid precipitation are prevalent;

4) develop a system of monitoring for solids accumulation; and

5) reevaluate this method when used for clay lined impoundment.

Additional research is needed to develop long term data on several actual impoundments using the level monitoring method of evaluating water balances. This would provide the EPA with the information necessary to establish guidelines for future surface impoundment monitoring plans. If the level monitoring water balance technique is required, consideration should be given to requiring a detailed documentation of impoundment dimensions following the completion of impoundment construction. This would allow a more accurate calculation of storage capacity for the impoundment and, consequently, the seepage value calculated would be more accurate.

C.4 MATERIALS AND METHODS

This section presents information about how the monitoring system for the water balance system was set up. Special equipment needed to conduct the study, such as the PVC pier, are discussed. A discussion of the operation of the instruments is included along with their associated error term and/or sensitivity setting. Also presented is the schedule used to monitor the system and alternatives to this schedule which might be considered.

C.4.1 Site Description

Research for this project was conducted on the campus of the Southwest Research Institute which is located on the southwest side of San Antonio, Texas. The site is characterized by gently rolling terrain and native vegetation. Climatic conditions for the area are summarized in Table C-1 which lists normal values for temperature, precipitation, and relative humidity from National Weather Service records for the period, 1941-1970.

The impoundment where the study was conducted is lined with high density polyethylene plastic and measures 61 x 61 m (200 x 200 feet) and is approximately 2.1 m (7 feet) deep (Figure C-1). It is situated on the side of a gently sloping hill with three sides constructed from elevated berms. Extending from the bottom of the impoundment is a discharge pipe to which an in-line flow meter was connected (Figure C-2) This type of flow meter should be positioned to ensure continuous, non-turbulent, full pipe flow. This was accomplished by raising the pipe that extended past the meter to a height which would maintain a constant head sufficient to ensure full pipe flow.

Table C-1. National Weather Service Climatic Normals for San Antonio, Texas for the Period from 1941 to 1970.

Month	Temperature		Wind Speed			Relative Humidity*				Precipitation
	Min	Max	Ave	Dir	Fast Mile†	00	6	12	18	
Jan	39.8	61.6	9.2	N	35	76	81	60	58	1.66
Feb	43.4	65.6	9.9	NE	35	75	80	57	53	2.06
Mar	49.1	72.5	10.6	SE	35	72	79	53	47	1.54
Apr	58.8	80.3	10.6	SE	39	77	83	57	52	2.54
May	65.7	86.2	10.2	SE	40	81	88	56	51	3.07
Jun	72.0	92.4	10.1	SE	35	80	88	56	51	2.79
Jul	73.8	95.6	9.2	SE	48	75	87	51	45	1.69
Aug	73.4	95.9	8.6	SE	35	74	86	51	46	2.41
Sep	68.6	89.8	8.5	SE	42	78	86	55	52	3.71
Oct	59.2	81.8	8.5	N	31	77	84	53	53	2.84
Nov	48.2	71.1	8.9	N	32	76	81	55	56	1.77
Dec	41.8	64.6	8.7	N	30	76	80	57	57	1.46
Year	57.8	79.8	9.4	SE	48	76	84	55	52	27.54

† Fastest sustained wind speed for one minute.
* 24-hour time.

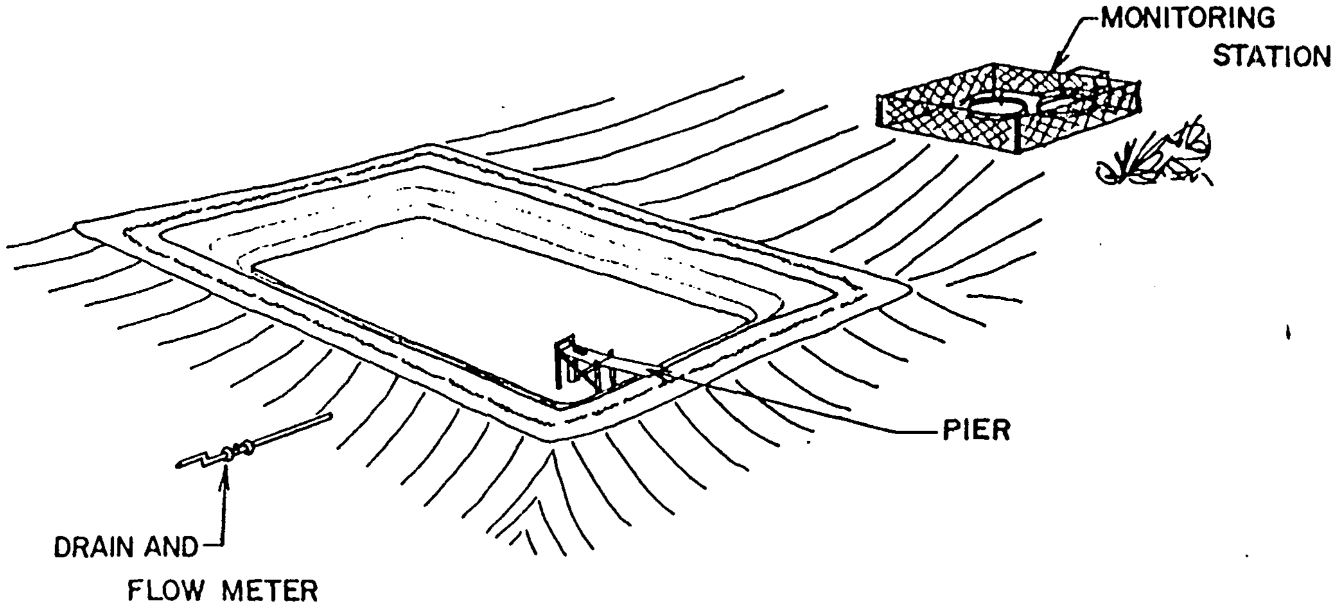

FIGURE C-1. SITE PERSPECTIVE OF STUDY AREA WITH MONITORING EQUIPMENT.

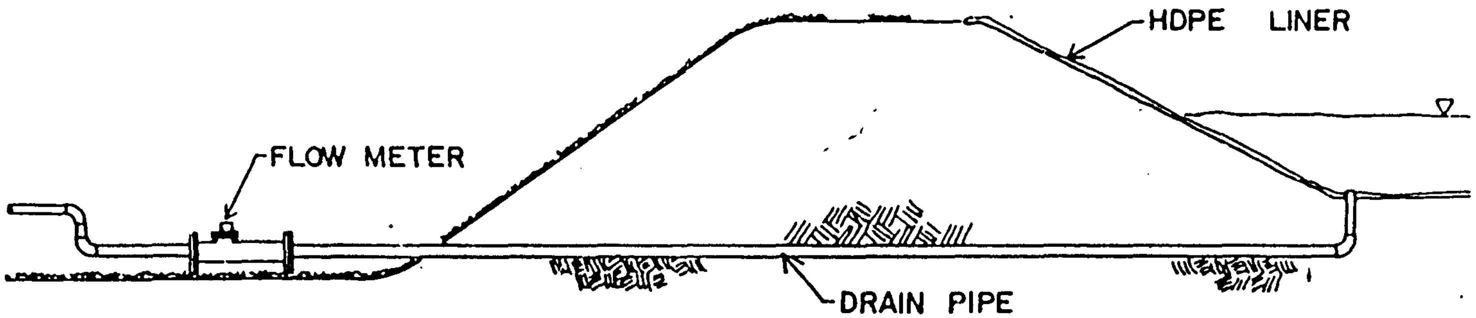

FIGURE C-2. IN LINE FLOW METER TO MEASURE DISCHARGE.

On the eastern side of the impoundment, a PVC pier was constructed to support the level recording device (Figure C-3). PVC was selected because of its resistance to corrosion and the light weight construction offered (by four-inch schedule 40) without sacrificing strength. Attached to the pier is a stilling well constructed from (10-inch inside diameter) PVC pipe (Figure C-4). The stilling well was mounted to the pier so that the upper lip was flush with the pier deck and the lower lip was several inches from the bottom of the impoundment. A baffle was installed in the lower portion of the stilling well. The baffle consisted of a 10-inch diameter plexiglass plate with a 1/4 inch hole in the center to which a flexible hose was connected. The plexiglass plate was mounted in position at the bottom of the stilling well and sealed by silicone caulk with the 1/4 inch flexible hose extending from the center hole. The hose was then coiled and placed on the bottom of the impoundment where it acted as a damping chamber to eliminate the effects of wind and wave action.

On the northern side, a monitoring station was constructed consisting of two evaporation pans with level recording devices, a precipitation gauge, and a data logger (Figure C-5). Both of the evaporation pans were buried in the ground with four inches of "freeboard" exposed. Each pan was then filled with water to the point that the water level was equal to the ground level. A stilling well was placed in both evaporation pans to improve the accuracy of the float recorder by removing unnecessary movement caused by wind and wave action. Each pan was covered by wire screen (2-inch mesh) to prevent access to the water surface by wildlife and to reduce the amount of debris that might blow into the pan. The level recorder for each evaporation pan was mounted on four-inch channel iron which was then placed across the edge of the pan. By placing the iron bar on the edge of the pan, errors that might result from settling of the pan or bar can be avoided (Figure C-6).

Precipitation at the site is measured by a tilting bucket rain gauge which is recessed in the ground so that the orifice of the gauge is flush with the ground surface. A splash guard, consisting of plastic garden edging, was placed around the orifice. The edging was pushed into the ground so that approximately one inch remained exposed. It was arranged in a spiral extending from the orifice outward to a distance of fourteen inches with each successive spiral being an inch and a half from the preceding spiral (Figure C-7). Grass was then planted between the spirals to stabilize the soil and to help prevent splash-in during a rainfall event.

A fence, of two-inch mesh chicken wire, was constructed to enclose the evaporation pans and rain gauge to prevent disturbance by wildlife. Outside the fence, an instrument shelter was constructed to house the data logger which was linked to the evaporation pan level recorders and the precipitation gauge. By placing the data logger in the shelter it was possible to shade the unit as well as ground it, to reduce any interference which might result from excessive heat or static electricity.

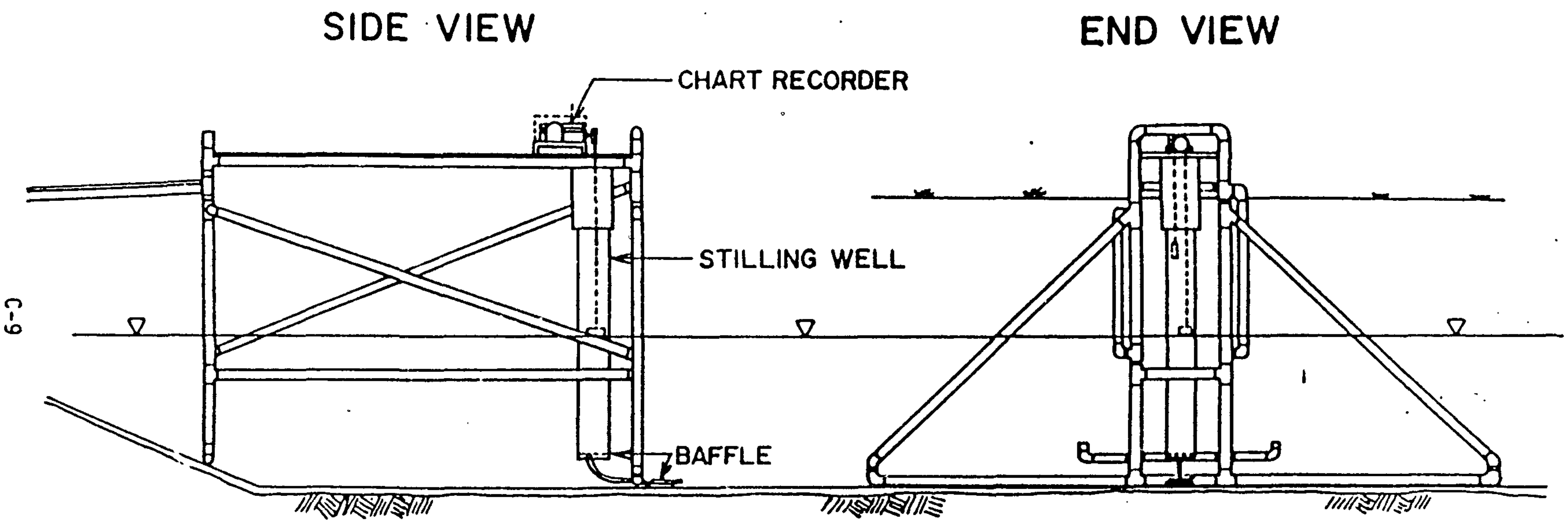

FIGURE C-3. PVC PIER WITH STILLING WELL AND FLOAT RECORDER.

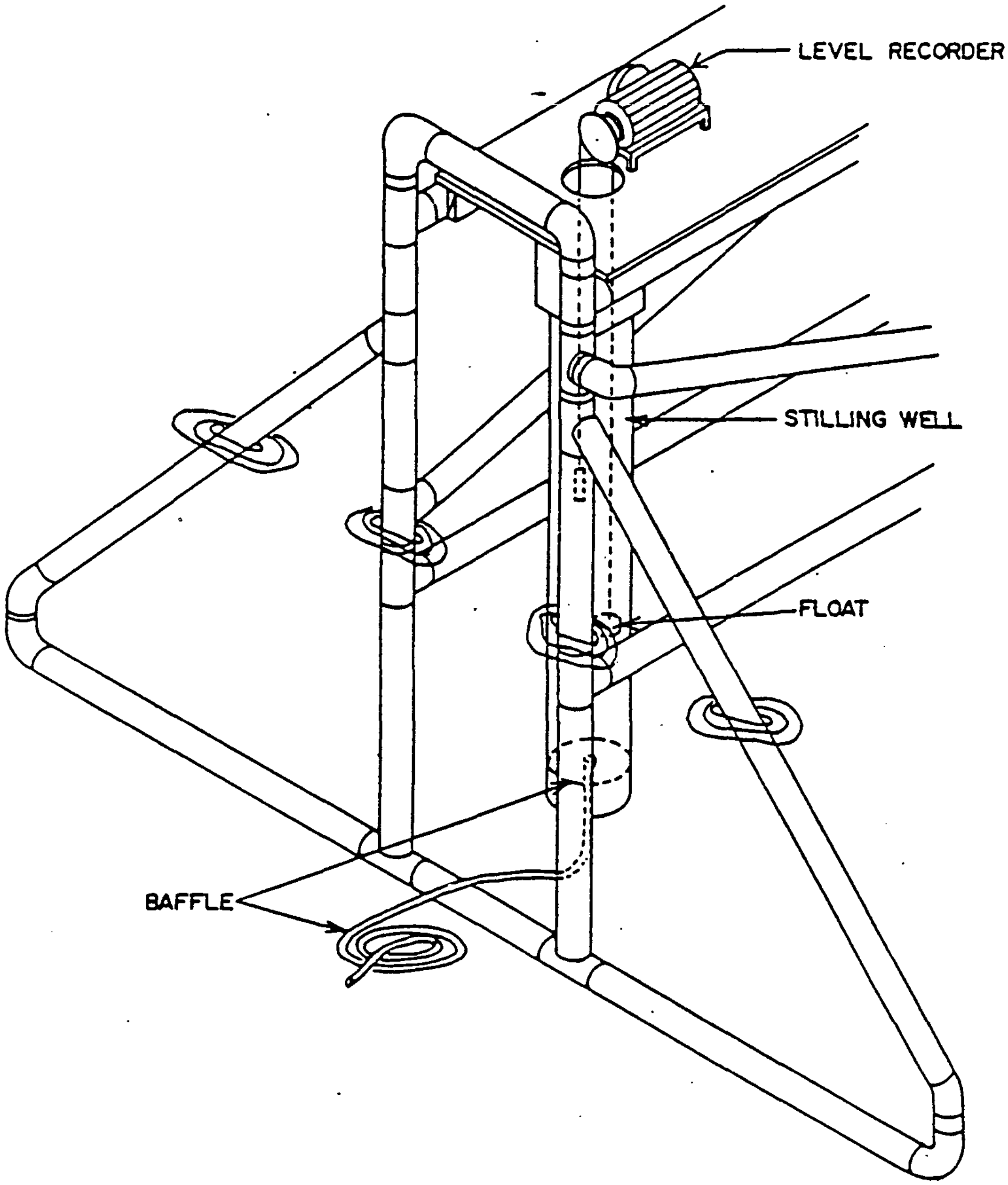

FIGURE C-4. CLOSEUP OF STILLING WELL WITH RECORDER.

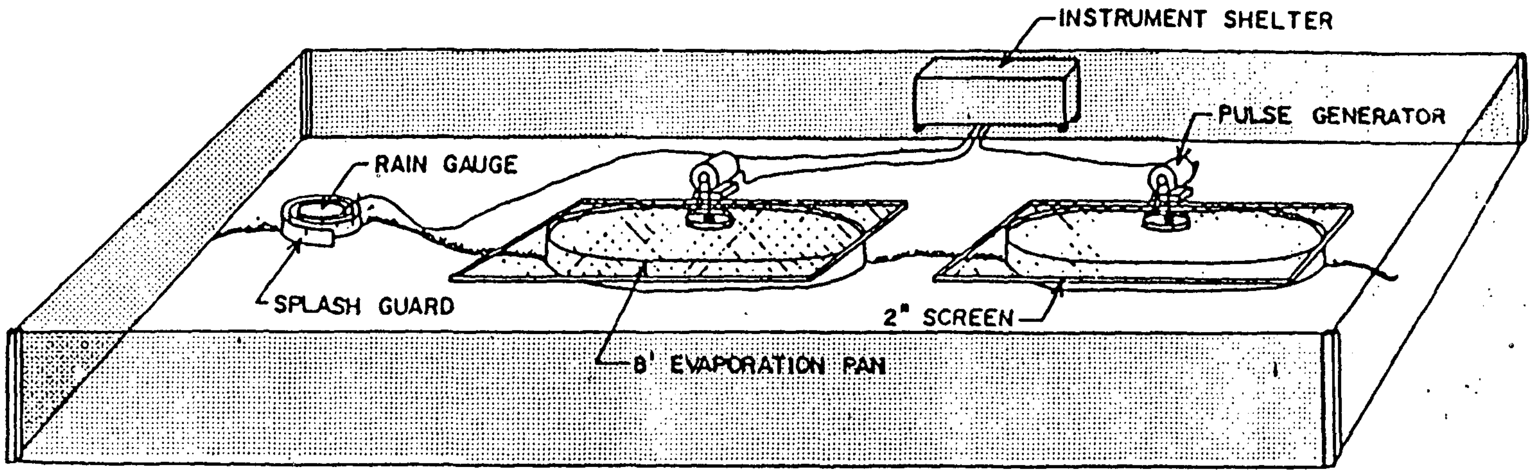

FIGURE C-5. PRECIPITATION AND EVAPORATION MONITORING EQUIPMENT.

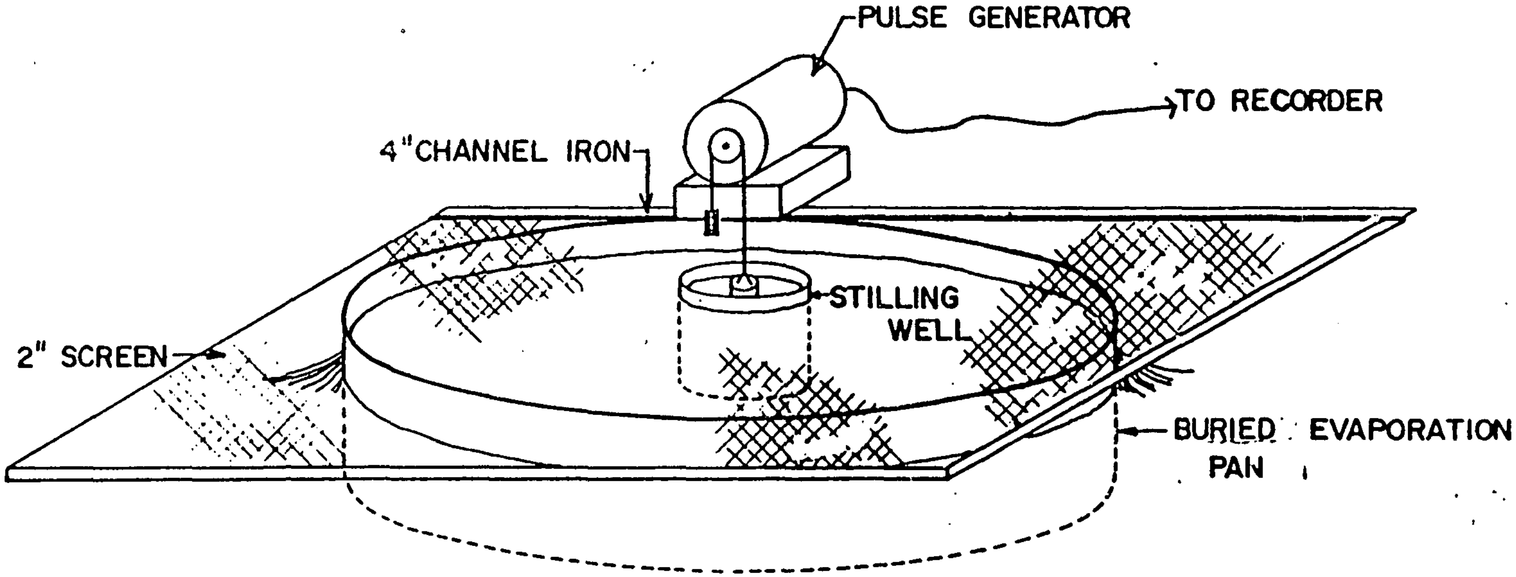

FIGURE C-6. BURIED EVAPORATION PAN WITH SCREEN COVER AND PULSE GENERATOR.

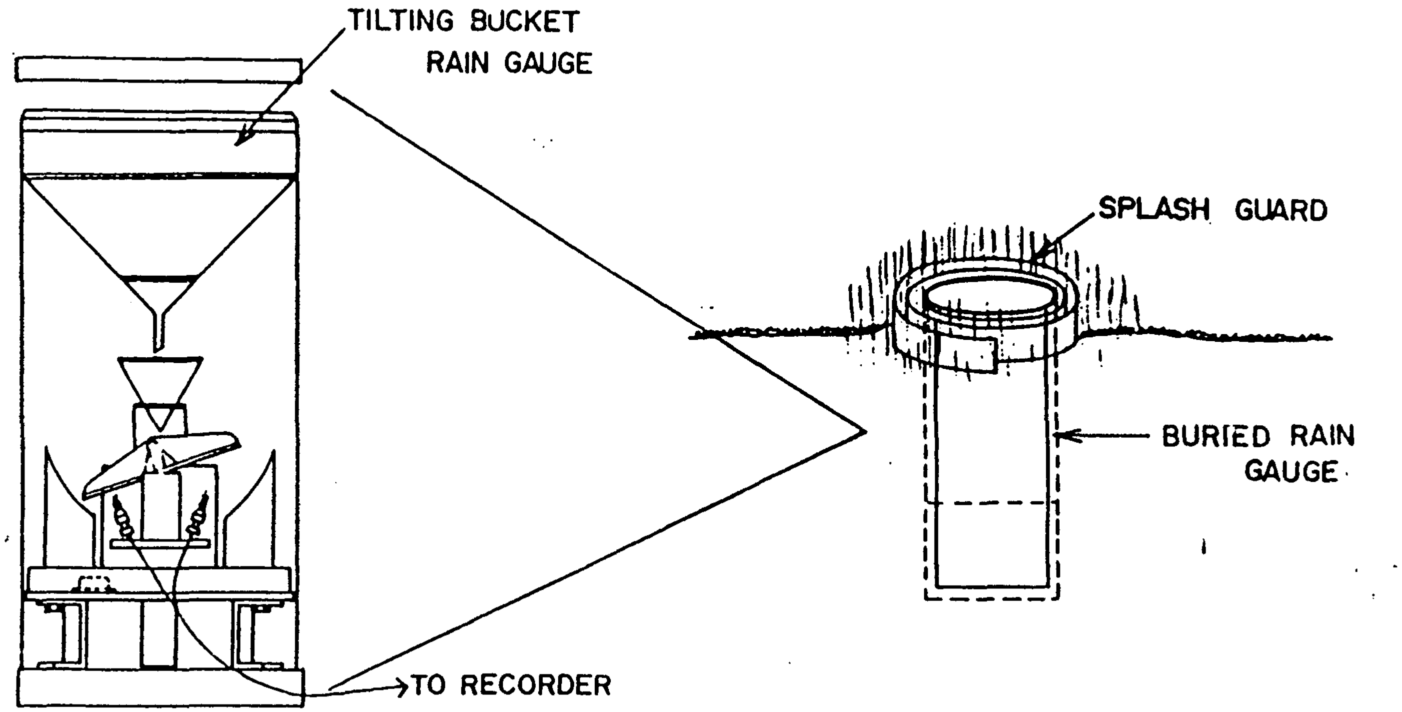

FIGURE C-7. TILTING BUCKET RAIN GAUGE BURIED AT GROUND LEVEL WITH SPLASH GUARD.

C.4.2 Study Instruments

The thrust of this section is to design a standard system which can be installed at any surface impoundment. A brief overview of each component of the system will be discussed as to how it fits into the system and why it was selected. In choosing the various components, the following criteria were used; accuracy, ease of operation, compatibility within the system, and cost.

For the initial study, the on site parameters which must be measured include precipitation, evaporation rates of the pan and the impoundment, and the values for the amount of waste added and discharged. For a more complete understanding of the climatic conditions affecting the study site, it will be necessary to measure and record several temperature values such as air temperature, and the temperatures of the waste in the impoundment and in the evaporation pans.

To maintain complete records with the required level of accuracy, it is necessary to use an automated system. The heart of this automated system will be the recorder. Advantages offered by a recorder include continuous monitoring, reduced maintenance, and removal of human errors or bias associated with taking measurements.

Precipitation, as mentioned before, is a difficult parameter to measure accurately. The accuracy of the measured value will depend on the type of gauge selected, the location of the gauge, and the type of precipitation measured. The type of gauge which should be used is a tipping bucket gauge. This type of gauge offers an unlimited capacity with accuracy and resolution values of 0.5 percent and 0.01 inches, respectively. By placing the gauge orifice at ground level, the recorded precipitation rate should express the "true" precipitation rate. It will be necessary to protect the gauge from splash in by placing a splash guard around the gauge. This type of system will be most effective if the predominate form of precipitation is rainfall.

Evaporation measurements are critical in that any error in measurement would have the tendency to mask or exaggerate the presence of a leak. The proposed system would include an evaporation pan which should be as large (and deep) as practical since the larger volume would be more representative of the impoundment. The pan should be buried near the impoundment with only four inches of the rim exposed above ground. By burying the system, daily fluctuations in temperature should be more representative of the impoundment. The evaporation rate should be measured by a float recorder which responds to small changes in the level of the waste. A float system is preferred over other systems because a float gives a direct measurement of the waste level regardless of the type of waste being considered. The accuracy of float systems varies widely but instruments are available that are sensitive to changes of less than 1 mm. Two level gauges will be necessary, one for the impoundment and one for the evaporation pan.

Waste addition and discharge values can accurately be measured by a simple flow meter which records total flow volume. The recorded value should be very accurate provided the metering system functions properly.

In selecting each of the instruments a conscious effort was made to select the best instrument based on accuracy, ease of operation, minimum maintenance, and reasonable cost. Instruments were selected to measure precipitation, waste inflow and outflow, and level changes of the impoundment and evaporation pan. The remainder of this section will deal with the individual instruments selected stating their specifications and mode of operations.

Waste inflow and outflow volumes are to be monitored by a Model MLFT-SGH-1 Main Line Flanged Tube Meter (3-inch) produced by Badger Meter Inc. of Milwaukee, Wisconsin. The tube is constructed of cast iron and is partially lined with stainless steel. Moving parts of the unit are sealed to prevent corrosion and are constructed from bronze, Graphitar, and high density plastic. Flow values are recorded by a sealed six digit totalizer which is accurate to within ± 2 percent of actual flow. Restrictions which govern the use of this unit are: 1) that 10 pipe diameters, 76 cm (30 inches), of unobstructed straight piping be placed before and after the tube meter to reduce turbulent flow; and 2) the pipe must be filled during flow to ensure accuracy.

For the initial study it was decided that two evaporation pans would be needed; one to measure the evaporation of water and the other to measure the evaporation rate of the waste. The evaporation pans will consist of two galvanized circular stock tanks which measure 2.4 m (8 feet) in diameter by 0.6 m (2 feet) deep. To record level changes of the two evaporation pans, a Data Acquisition System (DAS) will be employed which is produced by Leupold and Stevens, Inc. of Beaverton, Oregon. The DAS consists of a Hydromark data logger, a hand-held data programmer, a two stand alone pulse generators to measure level changes, as well as a tilting bucket precipitation transmitter. Accuracy of the pulse generators is 1 mm (0.003 foot) with a 1:1 gear ratio and a 7-day chart capacity. Power for the system will be provided by a 12 volt battery. Changes in the surface level of the impoundment will be measured by Type F Water Level Recorder which is also manufactured by Leupold and Stevens. The Type F Recorder is a free standing instrument sensitive to a level change of 1 mm (0.003 foot) with a 7-day chart capacity at a gear ratio of 1:1. Floats used on all three recorders measure 20.3 cm (8 inches) in diameter and were selected because of the increased sensitivity offered by the larger size. In addition to the larger size it was necessary to sue floats constructed from stainless steel to eliminate any complications associated with corrosive waste.

Precipitation will be recorded by Leupold and Stevens Tilting Bucket transmitter which is connected to the DAS. The tilting bucket system is accurate to 0.5 percent with a resolution 0.25 mm (0.01 inch) and has an unlimited capacity.

All of the above systems are designed to operate on DC voltage provided by a standard 12 volt battery, or they are free standing requiring no external power source. The overall system is designed to require maintenance only once every 7 days. Each component of the system is weather proof which eliminates the need to provide an instrument shelter.

C.4.3 Data Collection

Data were collected for a two-month period from mid-March to mid-May. During that time, the site was visited an average of once every seven days. Each visit consisted of acquiring data from three sources: the data acquisition system (DAS) which monitored level changes in the evaporation pans and the precipitation gauge; the float recorder used to measure level changes of the impoundment; and the in-line flow meter which recorded discharge volume through the drain line. All data collected during the study are presented in Section C-5.

The DAS is designed to accumulate and transmit data in an encoded digital format. Input to the data logger was from the two pulse generators and the tilting bucket rain gauge. The pulse generators were designed to respond to a level change of 1 mm. When this threshold was exceeded a signal was sent to the data logger where it was recorded. It is possible to either set the threshold of the data logger to an increment that is the same as the pulse generator in which case every signal is recorded, or set the threshold at some higher limit that would require several signals from the pulse generator before a value is recorded. Precipitation was measured in increments of 0.25 mm (0.01 inch). During a rainfall event, each tip of the rain gauge (0.25 mm) would send a signal to the data logger where the time of each pulse and a running total of the amount of precipitation would be recorded.

Information once stored can be obtained by interrogating the data logger by means of the hand-held programmer which presents the data one event at a time or by connecting the data logger to a compatible printer which will present a "hard" copy of the stored information. For this study the data were obtained by using the hand-held programmer.

Level changes of the impoundment were recorded by a mechanical float recorder which operates by means of a float pulley. The changes in water level were recorded by a pen which traversed the chart at a given speed as the float pulley rotated the drum chart. This type of system allows losses and gains in water volume to be recorded as well as the time that the event occurred.

Although this system was monitored once every seven days it would have been possible to monitor the instrument less frequently. The longest time frame that the impoundment float recorder can operate autonomously is limited by the maximum chart capacity of 32 days. The other instruments generally have the capacity to operate autonomously for greater than the 32-day period.

One limiting factor present in both the pulse generators and the impoundment float recorder is that of adequate float cable. These instruments operate by a float pulley which is driven by looping a cable around a pulley which is in turn connected to a float and counter weight. The cable used to operate the system must be sufficiently long to allow for the change in water level expected. For example, if the impoundment level is to be lowered by one meter (3.3 feet) there must be a minimum of one meter of free cable between the counter weight and the float pulley to accommodate the level change.

C.5 DATA INTERPRETATION

As previously described, the parameters measured included pan evaporation (in duplicate), impoundment level fluctuations, precipitation, and impoundment discharge. Meteorological observations (e.g., temperature, wind, and relative humidity) were obtained from the local San Antonio office of the National Weather Service. Data for the test period are presented in Table C-2.

C.5.1 Climatic Conditions

The climate during the study was typical of early spring in this region, characterized by periodic passage of maritime polar air masses on a three to four day cycle. Thus, a look at the record of temperature, wind, and relative humidity shows the expected wide fluctuations. Such changes in turn greatly affect the evaporative loss of water, as can be seen by comparing pan evaporation over time with a graph of temperature variations during the same period (Figure C-8).

Alternating between polar and tropical air masses influences evaporative losses in a number of ways. As just mentioned, air temperatures brought about by advection of air masses influenced the evaporative demand by altering the saturation vapor pressure of the air (i.e., the concentration of water vapor that can potentially be supported). These differences are slightly counteracted by the much lower vapor pressure usually associated with the polar air masses compared to humid tropical air. When evaporative demand was high due to warm to hot temperatures in the tropical air, the associated winds were relatively light. Since the rate of water vapor transported away from a surface also controls evaporative losses, light winds that limit advection and turbulent mixing decrease the evaporation losses. Topographic effects that are manifested by changes in wind direction may also have significant effects, as will be discussed later.

C.5.2 Evaporation

Since precipitation was only slight during the study, comparisons of pan versus impoundment evaporation can be arrived at quite easily. Graphs of evaporation for both pans (average) and the impoundment are shown in

Table C-2. Meteorological Data from the National Weather Service, San Antonio, TX, for the Study Period.

Date	Temperature (°F)			Wind Speed (mph)				Relative Humidity (%)			
	Min	Max	Ave	Ave	Peak Gust	Dir	Fast Mile	00	6	12	18
March 20	40	76	59	7.9	23	N	16	56	73	26	25
21	43	78	58	10.7	23	SE	18	63	73	27	31
22	56	76	61	13.0	26	SE	20	67	81	48	55
23	62	83	66	10.3	26	N	34	81	84	51	34
24	48	78	73	8.1	21	N	32	33	63	27	21
25	43	80	63	9.8	22	SE	17	54	73	37	43
26	62	86	62	8.0	16	SE	12	65	78	51	37
27	64	96	74	15.7	40	NW	30	81	87	12	14
28	47	70	80	19.3	39	NW	30	37	52	21	18
29	38	71	59	5.8	16	N	13	33	62	22	21
30	53	72	55	11.8	21	E	16	37	52	33	29
31	56	78	63	6.6	18	SE	12	77	90	57	50
April 1	56	72	64	11.9	23	SE	18	84	83	65	59
2	53	84	69	9.4	20	NW	16	84	90	55	24
3	46	83	65	11.1	26	NW	18	61	37	16	17
4	50	76	63	11.0	30	N	17	27	41	22	22
5	40	73	57	4.8	13	S	13	41	65	31	26
6	47	72	60	10.4	24	SE	16	49	69	59	68
7	62	73	68	10.5	22	SE	16	78	84	71	84
8	54	84	69	10.1	25	NW	21	87	75	34	26
9	48	91	70	9.0	21	SE	15	48	74	23	20
10	54	88	71	10.0	29	SE	20	51	77	12	19
11	52	88	70	7.7	17	S	14	46	69	22	24
12	54	82	70	8.7	27	N	20	51	77	31	31
13	51	89	70	7.2	16	S	10	42	49	39	31
14	52	81	67	13.9	26	NW	21	76	24	15	15
15	48	78	63	12.9	29	NW	22	35	35	20	17
16	46	79	63	10.9	29	NW	21	40	44	16	13
17	41	86	64	7.5	19	S	15	39	49	16	12
18	49	92	71	7.2	20	S	12	45	66	37	37
19	57	98	78	8.1	20	S	14				
20	70	94	82	12.9	31	S	17				
21	66	90	79	12.8	30	NW	18				
22	59	81	70	4.8	29	N	18				
23	55	85	70	7.6	23	[illegible]	14				
24	55	90	73	12.8	35	S	20				
25	54	82	65	12.6	31	SE	17				
26	70	96	83	10.7	25	S	14				
27	68	88	78	13.1	31	N	21				
28	66	87	77	8.3	20	SE	13				
29	68	93	81	13.9	31	NW	21				
30	59	78	69	12.1	26	N	17				
May 1	60	85	73	8.4	21	SE	15				
2	70	88	79	8.2	21	SE	13				
3	69	95	82	11.7	31	NW	18				
4	69	100	82	10.9	35	S	17				
5	73	100	87	12.7	29	S	17				

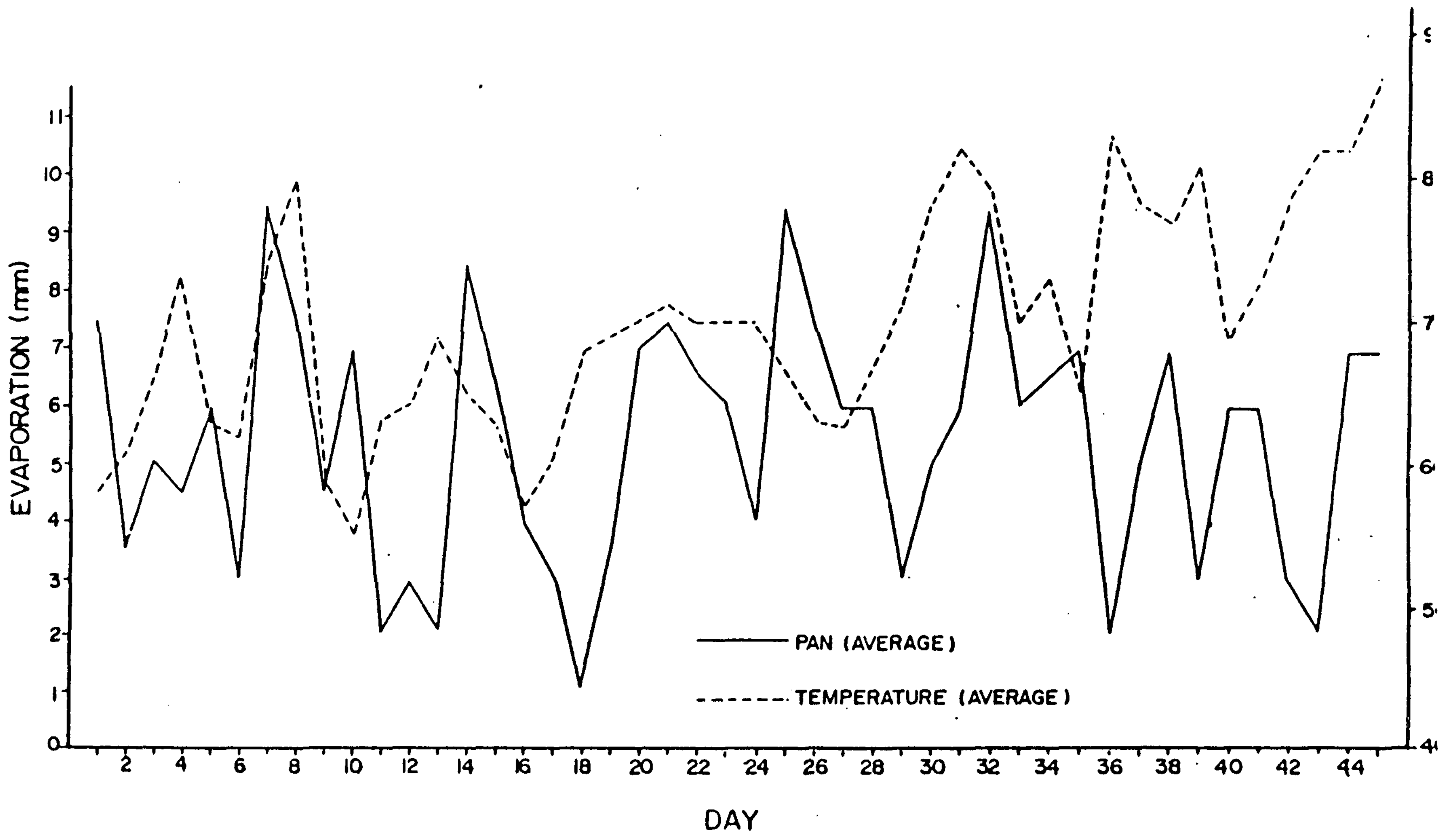

FIGURE C-8. DAILY EVAPORATION VALUES FOR THE EVAPORATION PANS RELATIVE TO THE AVERAGE DAILY TEMPERATURE.

Figures C-9 and C-10. Air mass effects are readily apparent and result in wide diurnal fluctuations. Thus, data should be expressed on a weekly or monthly basis to damp out these air mass effects and indicate broader trends. However, the daily data do allow a more detailed comparison of the pan versus impoundment evaporation rates.

The data are in agreement in that measurement of evaporation in both the pans and the impoundment changed at nearly the same time in response to changes in evaporative demand. The slight lags in the evaporation rate of the impoundment during periods of rapid heating (e.g., days 8 and 9, and days 15 and 16) are expected due to the larger heat storage capacity of the impoundment. In the early part of the study, the evaporation rate of the pan was less than or approximately equal to the evaporation rate of the impoundment. This is the expected relationship. What happened later in the study, was not expected. During the last three weeks of the study the evaporation rate of the impoundment exceeded that of the evaporation pans. The reason for this is that the level in the impoundment was several feet (approximately 5 feet) below the berm. At that point, the water in the impoundment was less than 0.6 meters (2 feet) deep. This low level coupled with the heat absorption capacity of the black liner allowed the water temperature to fluctuate more quickly. This resulted in more rapid increases and decreases in the evaporation rate of the impoundment.

During the course of the study, the level of water in the evaporation pans was allowed to drop. At no time during the study was any water added to replace that which was lost due to evaporation. The reasoning behind this was to mimic the low water level present in the impoundment. It is felt, however, that the lower water level in the evaporation pan set up a saturated air layer over the pan which reduced the evaporation rate disproportionally to that of the impoundment.

The pan coefficient for this study was 1.09. This value represents the average obtained over the 45-day period. It is felt that this value is too high and the actual value should lie between 0.90 and 1.00. Daily values for pan coefficients varied from 0.25 and 3.50 (Table C-3) while extremes for weekly pan coefficients vary from 0.80 to 1.19 (Table C-4 and Figure C-11). Variability of the daily and weekly pan coefficients differ in the magnitude of the range covered and it is felt that the longer the data are collected, the more accurate the pan coefficient will be.

C.5.3 Calculations and Error

In acquiring data, there is always an associated error due to the manner in which the data are collected or because of the inherent inaccuracy in the instruments used. The following discussion will present each term of the water balance equation and the associated error. Also included is an examination of several of the terms which can be disregarded in some situations.

The basic water balance equation for evaluating seepage consists of seven components and is written as:

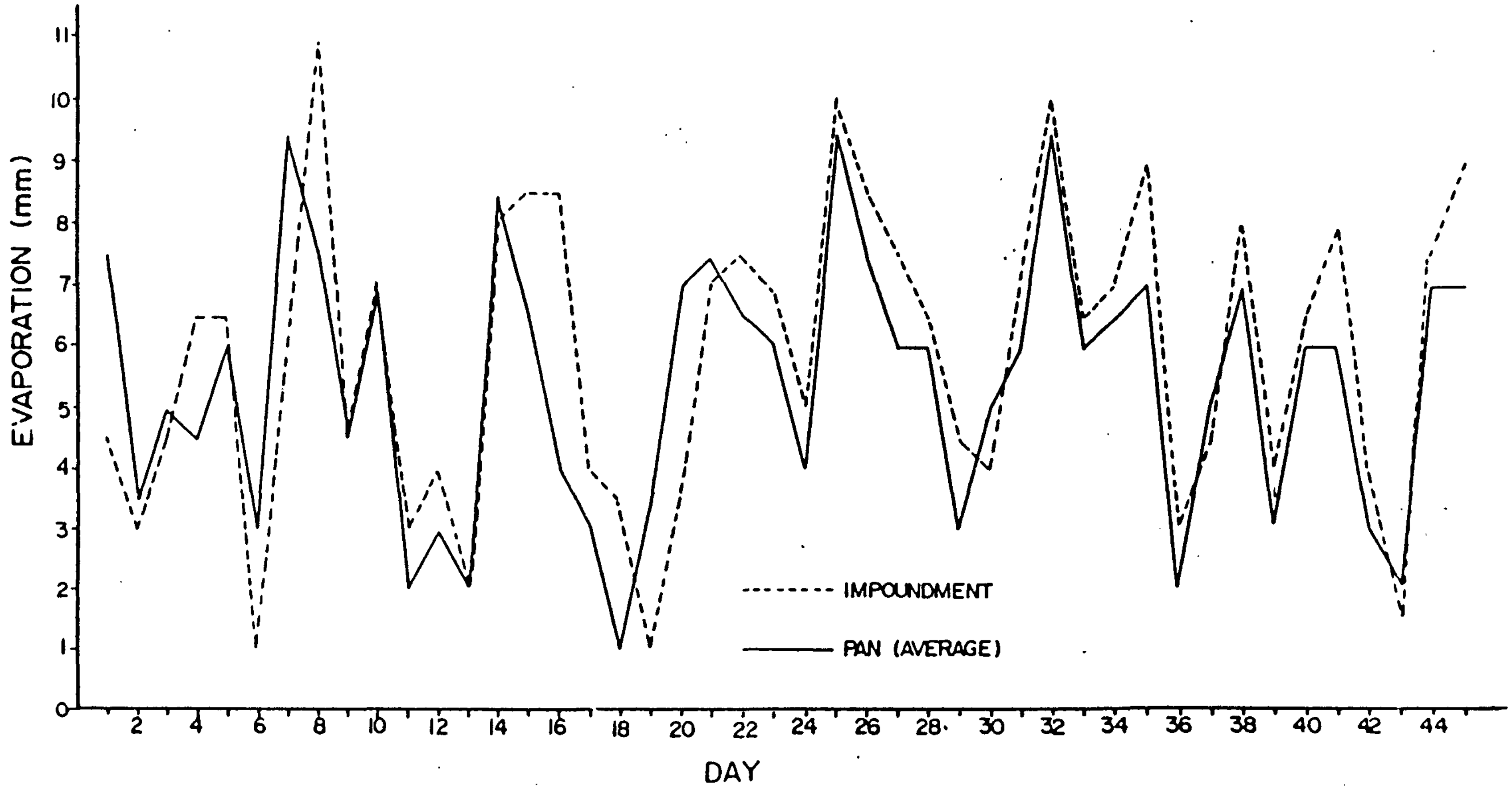

FIGURE C-9. DAILY EVAPORATION VALUES FOR THE SURFACE IMPOUNDMENT AND EVAPORATION PANS (AVERAGE).

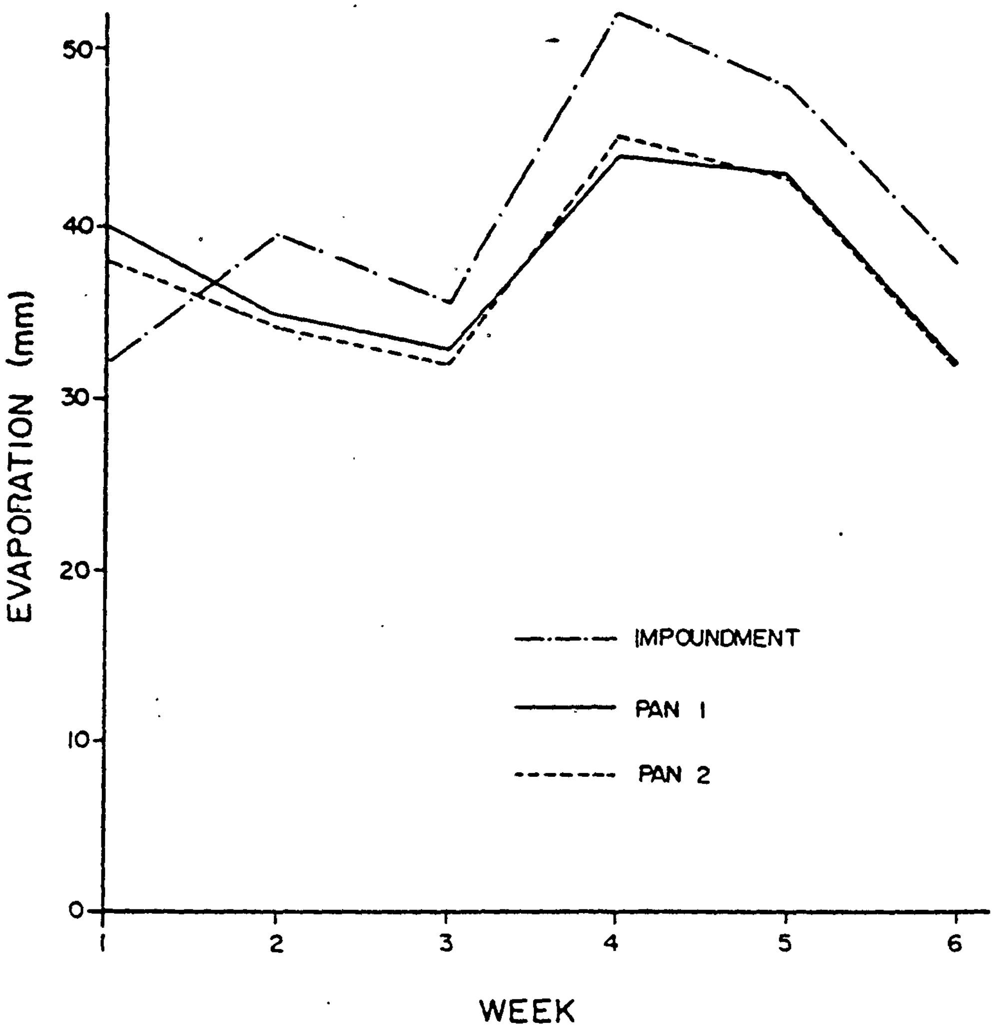

FIGURE C-10. WEEKLY EVAPORATION VALUES FOR BOTH EVAPORATION PANS AND THE SURFACE IMPOUNDMENT.

Table C-3. Daily Evaporation Data for Both Evaporation Pans and the Impoundment*

Date	Day	Pan 1 (mm)	Pan 2 (mm)	K_1	K_2	Impoundment (mm)
Mar 21	1	8	7	.56	.71	5.0
22	2	3	4	1.00	.75	3.0
23	3	5	5	.90	.90	4.5
24	4	5	4	1.30	1.63	6.5
25	5	6	6	1.08	1.08	6.5
26	6	3	3	.33	.33	1.0
27	7	10	9	.60	.67	6.0
28	8	7	8	1.57	1.38	11.0
29	9	5	4	.90	1.13	4.5
30	10	7	7	1.00	1.00	7.0
31	11	2	2	1.50	1.50	3.0
Apr 1	12	3	3	1.33	1.33	4.0
2	13	2	2	1.00	1.00	2.0
3	14	9	8	.89	1.00	8.0
4	15	6	7	1.42	1.21	8.5
5	16	4	4	2.13	2.13	8.5
6	17	3	3	1.33	1.33	4.0
7	18	1	1	3.50	3.50	3.5
8	19	4	3	.25	.33	1.0
9	20	7	7	.57	.57	4.0
10	21	8	7	.88	1.00	7.0
11	22	5	6	1.50	1.25	7.5
12	23	6	6	1.17	1.17	7.0
13	24	4	4	1.25	1.25	5.0
14	25	10	9	1.00	1.11	10.0
15	26	7	8	1.21	1.06	8.5
16	27	6	6	1.25	1.25	7.5
17	28	6	6	1.08	1.08	6.5
18	29	3	3	1.50	1.50	4.5
19	30	5	5	.80	.80	4.0
20	31	6	6	1.17	1.17	7.0
21	32	9	10	1.11	1.00	10.0
22	33	6	6	1.08	1.08	6.5
23	34	6	7	1.17	1.00	7.0
24	35	8	6	1.13	1.50	9.0
25	36	2	2	1.50	1.50	3.0
26	37	5	5	.90	.90	4.5
27	38	7	7	1.14	1.14	8.0
28	39	3	3	1.33	1.33	4.0
29	40	6	6	1.08	1.08	6.5
30	41	6	6	1.33	1.33	8.0
May 1	42	3	3	1.33	1.33	4.0
2	43	2	2	.75	.75	1.5
3	44	7	7	1.07	1.07	7.5
4	45	7	7	1.29	1.29	9.0

* Pan coefficients (K) are given which relate the pan values to the impoundment values.

Table C-4. Weekly Evaporation Data for Both Evaporation Pans and the Impoundment*

Week	Pan 1 (mm)	Pan 2 (mm)	K_1	K_2	Impoundment (mm)
1	40	38	.80	.84	32
2	35	34	1.13	1.16	39.5
3	33	32	1.08	1.11	35.5
4	44	45	.95	.93	42
5	43	43	1.12	1.12	48
6	32	32	1.19	1.19	38
Total	227	224	1.04	1.05	235

* Pan coefficients (K) are given which relate the pan values to the impoundment value.

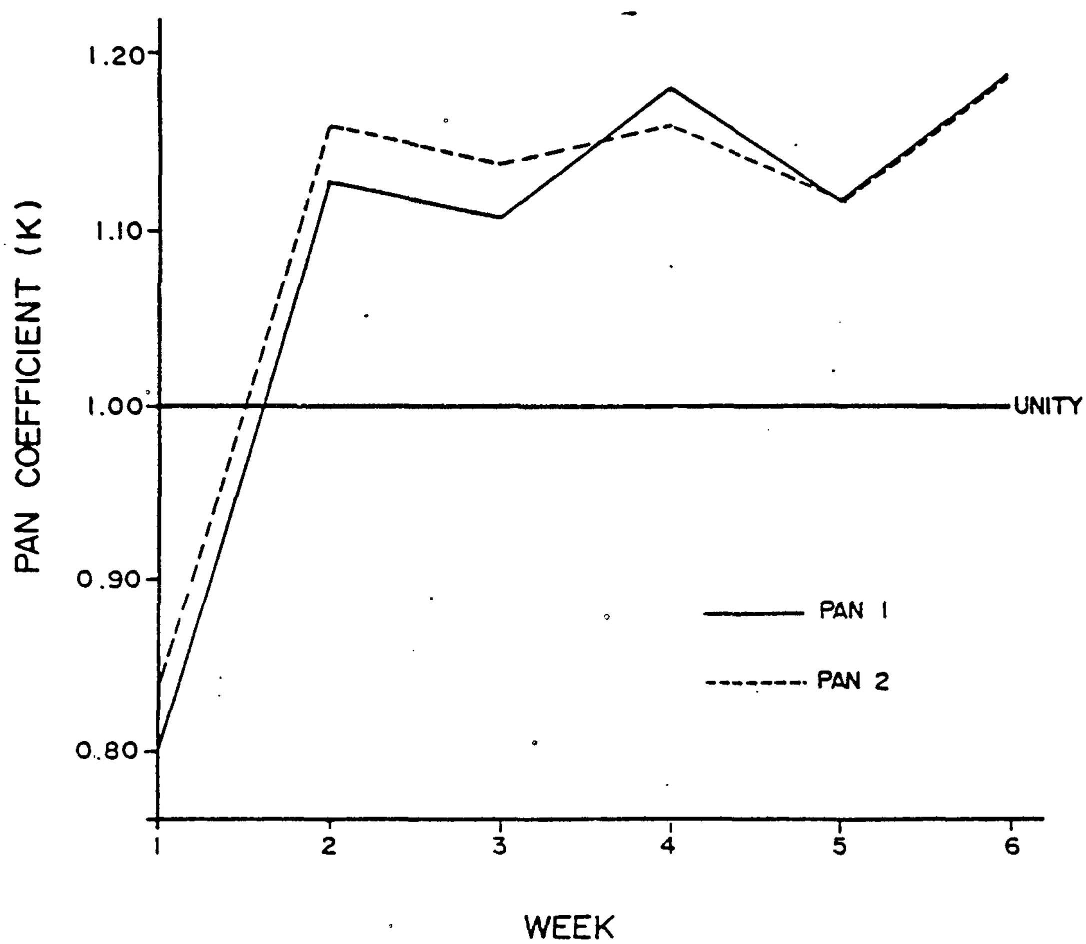

FIGURE C-11. WEEKLY PAN COEFFICIENTS FOR THE STUDY PERIOD FROM MARCH 21 - MAY 5. THE AVERAGE K VALUE FOR THIS PERIOD IS 1.09.

$$O_u = I_s + I_p + I_u - O_s - O_e - \quad S$$

where:

O_u = underground outputs or seepage
I_s = surface inputs or run-on and waste received
I_p = precipitation intercepted by the impoundment
I_u = underground inputs
O_s = surface outputs or discharges
O_e = evaporation losses
S = change in storage

Each component has an associated error term (n). It is necessary to define the limits of each error term as either a percent error or as a level of resolution or sensitivity.

Since O_u (underground output) represents the unknown parameter, the equation is solved in terms of the six known parameters. The sum of the error factors associated with the known parameters will equal the error factor for O_u.

In most cases underground input (I_u) will not be a factor since most surface impoundments are above the water table and, in situations where the impoundment might be in contact with the water table, the hydraulic head of impoundment would usually prevent water inflow. In this study, I_u is assumed to be zero and there would, therefore, be no associated error term for I_u.

The accuracy of measurements made of precipitation intercepted by the impoundment (I_p) is dependent on both the size of the impoundment and the accuracy of the rain gauge. For this study, a tilting bucket rain gauge with an accuracy of 0.5 percent was used. In addition to the error term associated with the instrument chosen, there is an error associated with the positioning of the rain gauge. By placing the rain gauge in a pit with its orifice at ground level, the expected error value due to placement was limited to to 1.5 percent (Bleasdale, 1958). Therefore, the total expected error value associated with measuring rainfall in this study is 2 percent.

Surface inputs (I_s) may be in the form of surface run-on or input of waste. In the case of surface run-on the magnitude of the resulting error will depend on the intensity and duration of the run-on event. Since, in most cases, run-on events are not metered, the magnitude of the resulting error is unknown. Ideally it is best to eliminate all possibility of surface run-on. If this is accomplished, the associated error value for run-on will be zero. When liquid is added to the impoundment, it should be directed through a metering device. During this study, a in-line flow meter was used which is accurate to ± 2 percent.

Surface output (O_s) is very similar to surface input in the sense that unmetered surface output should not occur. If unmetered output were to occur, the amount is likely not to be known. Consequently, the error value would also be unknown. If no surface output occurs, then there would be no associated error term. In this study, discharge of liquid was measured by the same meter that measured surface input, therefore, the error value of ± 2 percent also applies to the O_s term.

Output due to evaporation (O_e) in most situations is the hardest of the parameters to measure and usually has the largest associated error term. Evaporation during this study was measured by a float recorder which is sensitive to a level change of 1 mm. This degree of level measurement sensitivity yields an error of less than one percent. The main source of error in evaporation measurement, therefore, will result from using evaporation pans to estimate the evaporation rate of impoundments. This error term will vary from site to site and depend on the type of pan used. In addition, evaporation error will depend on whether it is calculated on the basis of daily, weekly, monthly, or yearly average evaporation data. The pan used in the study is very similar to pans which have pan coefficients of 0.92 to near unity (Brutsart, 1982). These values represent the conversion factor used to calculate evaporation from large bodies of water. For example, if the pan coefficient is 0.9 and 0.2 meter of water is lost from the pan, 0.18 meters would be the expected loss from the impoundments. Values for the pan coefficient obtained from this study vary from 0.25 to 3.5 on a daily basis to 0.80 to 1.19 on a weekly basis. The overall pan coefficient for the study was 1.09. This suggests that the longer the time period used to calculate the pan coefficient, the more accurate the value will be. It is felt that in this case 1.09 represents the upper limit on the pan coefficient. In most cases, the upper limit rarely exceeds unity (1.00) when the coefficient represents an annual average. The lowest limit seen on a weekly basis was 0.08. When two weeks of data were averaged the lowest value was 0.98. Consequently, a conservative estimate for the lower limit can be established at 0.90. In this case, the maximum error expected would be 10.0 percent.

Monitoring for changes in storage will be done in terms of changes in water level. The level change will be recorded by a level gauge which is sensitive to 1 mm. This means that the recorded value is always within 1 mm of the actual level of the impoundment. Therefore, the error term will be a constant which equals 1 mm.

By pulling all of these terms together the total error value can be calculated. The total calculated error value may change depending on events which occur during the observation period. For example, if no precipitation occurs, then the error value due to precipitation is zero. The water balance equaiton can now be stated as:

$O_u = (I_s \pm n) + (I_p \pm n) + (I_u \pm n) - (O_s \pm n) - (O_e \pm n) - (S \pm n)$ The value of n either represents the value of the paramter multiplied by the percent error for that parameter or is given as a constant error. Where a percent error is used, the magnitude of error will depend on the magnitude of the parameter being measured. Once a value for each parameter has been established and an error value determined for each, these factors are added to express the total error range for the underground output. If there is a decrease in storage that significantly exceeds the summation of the error terms, then there is a quantifiable volume of seepage. If the decrease in storage does not exceed the total error, then the leakage rate is too small to quantify by this method.

There are two ways to approach the water balance problem. One is to account for all the water in terms of volume. To do this every cubic meter in and every cubic meter out plus every cubic meter in storage is calculated. The second approach would be to represent a volume in terms of the water level.

The second approach of monitoring level changes was adopted for this study. This method has the advantage of eliminating error associated with calculating volume changes using the volume formula. An additional advantage is that the level recorders (with floats in stilling wells) can measure level to within 1 mm of the actual level. The main disadvantage is that the level recorders cannot distinguish between sources of outputs or inputs. For example, surface output (discharge) and evaporation are both losses and both are registered as a drop in level. It is possible to eliminate this problem if one recognizes the following:

1) evaporation is a long term event; and

2) surface output is normally a short term event which occurs over a known time period.

In a similar sense, increases in level due to precipitation and surface input can be measured since they are associated with known short term events.

In using the level monitoring method for calculating the water balance, it was necessary to establish a base line water depth in the impoundment. This value was measured to be 1.030 meters. Cumulative values for the water balance parameters measured during the study period are as follows:

$$I_s = 0$$
$$I_p = 0.0185 \text{ m}$$
$$I_u = 0$$
$$0_s = 0.4300$$
$$0_e = 0.2255$$
$$S = -0.6775 \text{ m}$$

The water balance equation with these values inserted is:

$$0_u = 0 + (0.0185 \text{ m} \pm n) + 0 - (0.4300 \text{ m} \pm n) - (0.2255 \text{ m} \pm n) - (-0.6755 \text{ m} \pm n)$$

The error value of 1 mm is the error term used in this calculation for I_p, 0_s, and S. This is because each of these parameters is measured by a float recorder which is sensitive to changes in level equal to 1 mm. The error term for 0_e will include the 1 mm value and the error value associated with converting the evaporation value of the evaporation pan to that of the impoundment. The conversion factor (K) established for this study was 1.09. It would be premature to define the error value associated with the pan coefficient. This is because the study period was too short to establish a reasonable average pan coefficient. For the sake of completing the calculation, an error value of ±10 percent will be assumed. (This value should be reduced significantly with the collection of longer term data.) Using that error, the pan coefficient will lie between 0.90 and 1.10, with the observed value of 1.09 lying near the upper limit of the error term. The n value for O_e will be (0.2255 m) 0.10 + 0.001 m. Therefore, n for O_e will equal 0.0235. Putting these values into the water balance equation gives:

$$O_u = (0.0185 \pm 0.0010\ m) - (0.4300\ m \pm 0.0010\ m) - (0.2255\ m \pm 0.0235\ m) - (-0.6755\ m \pm 0.0010\ m)$$

$$O_u = 0.0385\ m \pm 0.0265\ m$$

From these data, a leak is suggested which may be as large as 0.0650 m or as small as 0.0120 m. Additional data would be needed to substantiate this finding by statistical analysis.

C.6 REFERENCES

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APPENDIX D

METHODS FOR DETECTING LIQUID LEVEL

TABLE OF CONTENTS

D.1 INTRODUCTION

As discussed in Section 4.0, liquid level control consists of a four phase system, with level detection consisting of the primary and measuring elements in the sequence. The following sections discuss various types of level detection systems and offer information on their operation, the advantages and disadvantages of these systems, and such specifications as accuracy and generalized price. A quick reference to the types of systems discussed is provided in Table D-1.

In most of the following sections, information concerning the type of electrical output is absent. This is because the type of output signal for most liquid level sensors consists of a 4 to 20 mA signal, where the lower power setting represents the off signal and the higher power setting represents the on signal. This type of output is standard within the industry and is easily adaptable to most types of electrical controlling systems. In situations where a different output signal is required, engineering changes are possible to allow the level sensing device to interface with the level controlling elements. Therefore, the type of output signal omitted by the liquid detection devices should be adaptable to the system selected.

D.2 CAPACITANCE PROBES

Principle of Operation

This type of system operates on the ability of the unit to measure the ratio of a stored electrical charge for a given potential difference between two terminals separated by an insulator with a known dielectric constant. Typically, the probe forms one terminal or plate, and the sidewall of a metal pipe of stilling well forms the other. As a microelectric current is passed through the system, changes in the capacitance are measured as a function of the differences in the dielectric constants (K), which register a signal proportional to the length of the probe covered by the vapor phase (K_1) and the liquid phase (K_2).

Considerations for sizing a probe include the diameter of the pipe or stilling well, the dielectric constant of the liquid, and special coating used on the probe, if any. To use a capacitance probe in an impoundment, it will be necessary to mount the probe in a conductive shield which will serve the same function as the sidewall of a tank.

Capacitance probes have the ability to continuously measure liquid level and provide an analog output of 4-20 mA. They are equally capable of operating point relays to be used as high level or low level indicators. These point relays could be engineered to activate secondary liquid level control systems such as pumps, valves, or alarms.

Table D-1. Liquid Level Detection Systems.

System	Application	Principle of Operation	Advantages	Limitations
Capacitance	Non-corrosive wastes; corrosive w/mod	Measurement of stored electrical charge	Fail safe operation, easy operation	Based on liquid dielectric constant, affected by coating
Conductivity	Non-corrosive, conductive mat'ls	Completion of circuit through the liquid	Easy installation, inexpensive	Primarily point level only, requires conductive liquids
Diaphragm	Non-corrosive and corrosive wastes	Measurement of pressure increase due to liquid head	Diaphragm does not contact liquid, unaffected by minor surface agitation	Poor sensitivity to small level change, based on liquid density
Differential Pressure	Non-corrosive and corrosive w/mod	Measurement of pressure difference between liquid bottom and atmospheric	Sensor does not contact waste	Based on liquid density
Displacers	Non-corrosive wastes, corrosive w/mod, non-coating wastes	Measurement of force of displaced float, converted to depth	Used for continuous level monitoring, can detect interface	Must be calibrated for each liquid, based on density
Floats	Non-corrosive and corrosive waste w/ mod	Float remains in contact w/liquid surface to measure fluctuation	Continuous level monitoring, inexpensive	Constant contact w/ waste, affected by surface agitation
Impedance Probe	Non-corrosive, coating wastes, corrosive w/mod	Same as capacitance w/ shielding to overcome coating affects	Not as affected by coating wastes, no moving parts	Dependent on dielectric constant, relatively expensive
Level Gauge	Non-corrosive and corrosive wastes	Basically visual level monitoring and recording from gauge	Direct level measurement, inexpensive	Requires technician, difficult to incorporate into secondary controls
Infrared Sensors	Non-corrosive, non-coating and some corrosive wastes	Detection of reflected or refracted light	Very sensitive, safe in flammable liquids	Fouled by coating, expensive, basically point level sensing
Resistant Tapes	Non-corrosive and corrosive wastes	Contact of two elements due to pressure of rising liquid	Continuous level monitoring, not usually affected by coatings	Density sensitive
Thermal Sensors	Non-corrosive, non-coating liquids	Detect temperature between probe and liquid or vapor	Continuous level monitoring, accuracy	Density sensitive, affected by coating
Ultrasonic	Non-corrosive and corrosive	Reflection of ultrasonic beam to liquid surface	Does not contact liquid, continuous level monitoring	Inaccuracies due to surface turbulence or foam

Advantages and Disadvantages

Advantages include ease of installation and operation, versatility, a relatively inexpensive price, and availability. They may be coated with materials which are resistant to hostile environments, and are engineered to function safely near explosive or ignitible materials.

Disadvantages include the probe's dependence on the dielectric constants of the waste. The dielectric constant is different for most wastes and is sensitive to changes in temperature. The changing dielectric constant in impoundments which receive wastes that vary slightly in composition and consistency will compromise the accuracy of the probe. The probe is also subject to error due to coating, which may cause a false signal.

Range of Operation

Capacitance probes can be engineered to virtually any length for continuous liquid level measurement. Also available are high level and low level probes which sense critical liquid levels and have the capability to activate secondary level control systems. Normally, capacitance probes are designed to operate in storage tanks, but they can be modified for operation in open environments. Protective coatings are available for probes which will come in contact with corrosive or "sticky" materials.

Specifications

Costs: $250 - $450 for high level or low level switches
$350 - $700 (and up) for continuous level probes; cost increases as the length of the probe increases; special coatings would be an additional cost

Accuracy: up to ±1%

References: Bailey, 1976
Liptak and Venczel, 1982
Reason, 1984
Siegwarth, 1981

D.3 CONDUCTIVITY PROBES

Principle of Operation

Conductivity probes work on the principle of passing an electrical current through a conductive material. The probe(s) is situated at a critical point above a liquid and "actively monitors" the absence of a conductive liquid by maintaining an open circuit. When the level of the liquid comes in contact with the probe, the circuit is closed, thus causing a relay to activate a secondary level control system.

Advantages and Disadvantages

Conductivity probes have no moving parts and are extremely easy to install and operate. They operate on simple electrical current and require no encoding of an output signal. Typically, they are among the most inexpensive level detection system available.

Conductivity probes have limited use in liquids which are highly conductive. They are also influenced by the wave action and presence of foam on top of the liquid. Inherent difficulties arise by passing an electrical current through a liquid which is ignitible or explosive. Electrolytical corrosion and build-up of material on the probe are possible, and will cause the probe to fail.

Range of Operation

Conductivity probes are incapable of continuous level measurement, but are commonly used as high or low level indicators. The probes are limited in their use in highly conductive liquids or bulk materials.

Specifications

Cost: typically under $400

Accuracy: approximately ± 1/8 inch for on-off actuation

References: Belsterling, 1981
Hall, 1978
Liptak and Venczel, 1982
Scott, 1972

D.4 DIAPHRAGM DETECTORS

Principle of Operation

Diaphragm detectors operate on the simple principle of detecting the pressure exerted on a sensitive membrane. The pressure sensitive switch is usually mounted on the top of a riser pipe which extends into the liquid to be monitored. The riser pipe is sealed at the top by the pressure switch and is open at the other end, which is submersed in the liquid. As the liquid level rises, the air isolated in the riser pipe is compressed. The increased air pressure is recorded as a positive level change. As the liquid level drops, the air pressure in the riser pipe is reduced, which results in a decreased reading by the pressure switch.

Advantages and Disadvantages

The advantages of diaphragm devices include low cost and ease of operation. They are adaptable to use with many types of liquids, including corrosive wastes, since the diaphragm does not come in contact with the material. Reports by industry indicate these types of switches are reliable.

Disadvantages include poor sensitivity to small level changes, which limits the accuracy of these devices. Since the actuating mechanism is dependent on pressure, and since pressure is a function of the density of the liquid, variations in liquid composition may lead to error in level calculations. Additionally, temperature variations may be sufficient to alter liquid density, which could affect the accuracy of the instrument.

Range of Operation

Diaphragm devices provide continuous level monitoring with the capability of sensing high and low critical levels. Continuous level monitoring is virtually unlimited. Some devices are limited to riser pipes which do not exceed 60 feet and are designed for use in atmospheric tanks. Electronic sensors operate over ranges of 0 to 1.5 meters and pressures of 0 to 300 psig (gauge pressure in pounds/inch^2).

Specifications

Costs: $100 to $500 for mechanical diaphragm devices, $750 to $1500 for electronic devices

Accuracy: Poor; $\pm$ 1-6 inches for mechanical; $\pm$ 0.3% full scale for electronic devices

References: Hall, 1978
Lawford, 1981
Liptak and Venczel, 1982
Cheremisinoff, 1981

D.5 DIFFERENTIAL PRESSURE DETECTORS

Principle of Operation

Liquid level detection by differential pressure is an indirect method based upon measurement of the difference in pressure between the bottom of the liquid column and atmospheric pressure. Simply, two pressures can be sensed, one atmospheric and one at the bottom of the liquid column, and the difference taken. Knowing the density of the liquid, the depth can then be found. In practical applications, it is common to use a single pressure difference sensor to ensure the intrinsic balance of the static pressure levels. This arrangement will eliminate the inherent inaccuracies and problems associated with two independent pressure sensors.

Several types of differential pressure devices are available, including dry force balance and dry motion balance designs and manometers. Most devices employ a flexible diaphragm, bellows, liquid column or other insulating mechanism between the high and low pressure sides. As the level of the liquid increases, pressure on the high side of the sensor increases and movement of the insulator occurs in response to the pressure increase. Insulator movement is mechanically or electronically interpreted as pressure change, and the differential is calculated and converted to liquid level. The signal may also be used to trigger controlling devices and alarms.

Advantages and Disadvantages

Advantages of the differential pressure device include its adaptability to a wide range of wastes and situations, as well as easy calibration and operation and ability for continuous level monitoring. The mechanism is generally sealed and does not come in direct contact with the waste. It is also unaffected by material conductivity, foam and minor surface agitation.

Disadvantages include its dependence upon the density of the liquid. The unit must be recalibrated for each new waste according to the density of the waste. Furthermore, the system is typically not applicable for detection of a liquid-liquid interface.

Range of Operation

Differential pressure devices are used for continuous level monitoring of a wide variety of wastes. The devices are not, however, recommended for corrosive or hard to handle wastes. The system is applicable for storage and disposal impoundments containing non-corrosive wastes.

Specifications

Costs: moderate to high; $200 and up for local indicators, $600 and up for transmitters

Accuracy: up to $\pm$ 1/2%, dependent upon the system and the depth of liquid

References: Duncan, 1979
Lawford, 1970
Lawford, 1981
Liptak and Venczel, 1982

D.6 DISPLACERS

Principle of Operation

Displacer level detectors operate on the Archimedes' principle, which states that an object, when partially or completely submerged, will displace a volume of liquid whose weight is equal to the buoyant force exerted on the object. If the object (displacer) is connected to a weight sensitive device, any change in the displacers weight due to contact with a liquid can be detected. Depending on the shape and density of the displacer and the density of the liquid, specific measurements for either a continuous or a high/low level can be made.

For continuous level measurements, an elongate displacer (torque tube) with a known weight and shape is used. As the displacer is submerged, the weight of the displacer is reduced and the liquid level can be calculated proportional to the submerged depth.

High/low level measurements can be made using a flattened disc shaped displacer which registers a buoyant force when it comes in contact with a liquid surface. This type of displacer will detect discrete level changes as well as registering boundaries between layers which have different densities. When operated with a pulley system this type of displacer can be lowered to the liquid surface at regular intervals to take measurements and then be retracted.

Advantages and Disadvantages

The main advantage of this type of system (disc displacer) is its ability to detect varying layers of different densities.

Disadvantages include the need to carefully calibrate the displacer to the situation. This calibration is dependent on the density of the liquid, therefore, a variation in density will result in error when measuring the liquid level. Also, since the displacer has a known critical weight, anything which would change this weight, such as coating it with a viscous material, will alter the displacer's accuracy.

Range of Operation

Torque tube displacers can operate up to ranges of ten feet. Disc displacers are virtually unlimited in the range they can measure. Displacers can be designed to operate in open or closed environments.

Specifications

Costs: \$500 - \$1,500 depending on engineering specifications.

Accuracy: ± 1/2%

References: Bailey, 1976
Hall, 1978
Liptak and Venczel, 1982
Young et al., 1975

D.7 FLOATS

Principle of Operation

The operation of float actuated level detection devices is based upon the movement of a float with the rise and fall of the liquid level it is in contact with. The float movement is translated by various means into a number of control actions. Float devices are traditionally applied to liquid surface detection, but can be modified for liquid-liquid interface detection. Many float actuated designs are available and most operate using a buoyant sphere or disk.

Float and lever designs employ a float which is attached to a lever arm or mechanism. When the float moves up or down, the level arm activates a controlling element or output device. This type of device is generally fixed and is used as a point-level indicator.

Chain and tape level monitoring devices consist of a float connected with a flexible tape or chain to an uptake reel or wheel. The reel is connected to a level recording or detection mechanism. The float remains in constant contact with the liquid surface, thus enabling the level recorder to give continuous level monitoring as opposed to point-level detection. The float may also travel along vertical guide wires. Switches can be located at desired elevations along the guide wires to trigger pumps or valves as well as alarms or other warning devices and for the purpose of volume control.

Advantages and Disadvantages

Advantages of the float level devices include simple and easy operation and adaptability to many situations. They can be relatively inexpensive, and measure the liquid level directly.

Disadvantages include constant contact with the liquid, which limits its applicability with corrosive wastes. Floats are also affected more by waves or surface turbulence than some other methods unless stilling wells are used.

Range of Operation

Float level devices may be used for point-level or continuous level detection and monitoring. They are generally used for tracking the liquid surface but can be modified for monitoring a liquid-liquid interface. They can also be constructed of materials suitable for use in hostile environments.

Specifications

Cost: generally low to moderate; $200 and up

Accuracy: in the range of 1%, with greater accuracy in the more expensive systems

References: Cheremisinoff, 1981
Liptak and Venczel, 1982
Sandford, 1978
Scott, 1972

D.8 IMPEDANCE PROBES

Principle of Operation

Impedance probes operate on the same principle as the capacitance level detection systems. Capacitance probes, unlike impedance probes, incur problems with wastes which are sticky and tend to build up. To overcome problems caused by waste build up, impedance probes employ a capacitance probe which is surrounded by, and insulated from, a secondary probe. The secondary probe is in turn insulated from the liquid (Figure D-1). In the capacitance probe, build up from the liquid completes the

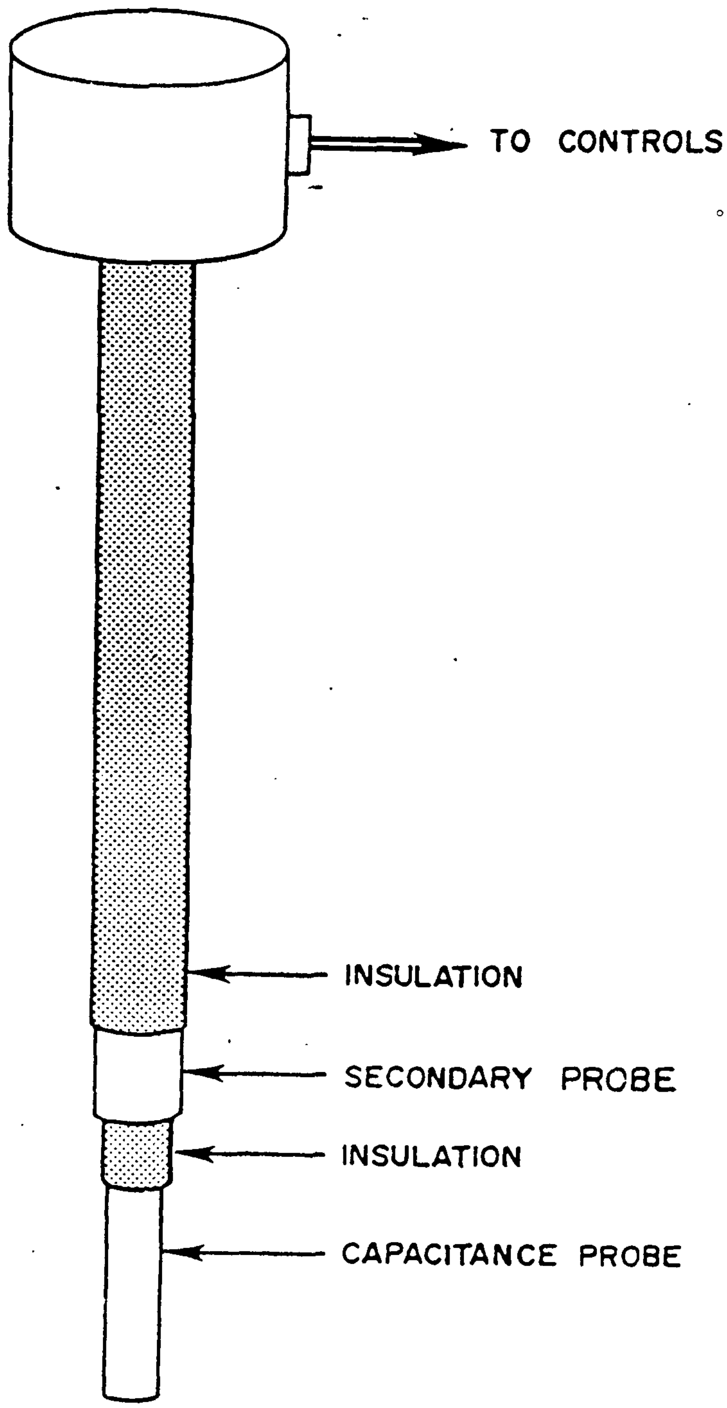


FIGURE D-1. IMPEDANCE PROBE.

circuit between the probe and containment wall by a low resistance path through the waste. Since a low resistance path results in a "positive" reading, waste build up will cause a normal capacitance probe to fail.

The impedance probe was designed to "short circuit" the low resistance path caused by waste building up. The low resistance path is isolated from the capacitance probe by passing an electrical current through the secondary probe. The integrity of the capacitive path is then preserved, allowing the probe to function normally regardless of waste build up. When the liquid level rises and comes in contact with the probe, the capacitance path is completed by the internal capacitance probe. This output can be used to engage the system design (pump, alarm, etc.). The added features of the impedance probe make it applicable to a wider range of wastes than the standard capacitance probe.

Advantages and Disadvantages

Advantages of the impedance probe include its ability to handle sticky build up of wastes on the probe. The impedance probe also has the advantage of no moving parts, therefore, it requires less maintenance than mechanical systems.

Disadvantages of the impedance probe include its dependence on the knowledge of the dielectric constant and conductivity of the waste. Changes in these waste characteristics will affect the accuracy of the device. The thickness of the coating which may build up on the probe can also have an effect on the accuracy of the unit. Impedance probes are also not well suited for non-conducting materials.

Range of Operation

Impedance probes are well suited for sticky, conductive wastes which tend to build up on the probe. The probe insulators can be designed to withstand many corrosive wastes and are used for point-level and continuous level monitoring. The probes are applicable in storage and disposal impoundments containing corrosive and some non-corrosive wastes.

Specifications

Cost: generally high; $700 and up for fixed point-level units; $1100 and up for continuous level probes

Accuracy: dependent upon probe sensitivity and waste characteristics

References: Liptak and Venczel, 1982

D.9 LEVEL GAUGES

Principle of Operation

Visual level gauges have been used for many years and are an inexpensive and reliable method of level indication. However, this method usually requires the efforts of a technician to correctly read and record the liquid level and to recognize levels which require action. Visual techniques include staff gauges from which the liquid level is read directly. The staff gauge may be permanently set within the impoundment or be a gauge which is placed in the liquid when a level reading is desired. Another level gauge uses a tape and plumb bob to measure the depth from liquid surface to a known elevation. A more sophisticated visual technique is a magnetically coupled gauge in which a float travels along with the liquid surface. A magnet, attached to the float, moves up and down a guide, triggering a column of indicators which relate to liquid level. All of these techniques are relatively inexpensive and easy to install and operate, but lack the automation which is at times desired or required.

Advantages and Disadvantages

Level gauges are easy to operate, are usually inexpensive, require very little maintenance, and many measure the liquid level directly. They are also available for many corrosive wastes.

Disadvantages include the need for personnel to read the liquid level and the lack of automation for full time level monitoring. Most of the techniques are also not readily applicable to any form of secondary function, such as triggeri- ..ips or alarms. Due to these problems, it is not recommended that these ..pes of level gauges be considered for use at hazardous waste surface impoundments.

Range of Operation

Level gauges are applicable to storage and disposal impoundments containing non-corrosive and some corrosive wastes. Continuous level measurement is the general rule, but as previously mentioned, any level measurement requires routine monitoring by on-site personnel.

Specifications

Cost: low to moderate; $100 and up dependent upon the system

Accuracy: dependent upon the system and personnel making measurement

References: Belsterling, 1981
Liptak and Venczel, 1982
Young et al., 1975

D.10 INFRARED SENSORS

Principle of Operation

Infrared sensors detect liquid level using the principle of refracted light, as defined by Snell's law. Snell's law defines the behavior of light when it contacts a boundary between two substances when each substance exhibits a different index of refraction. When light passes from one substance to the other, the light is refracted at a predictable angle based on the indices of refraction of the two substances.

This principle is used in infrared sensors where a light beam is passed through a conical tipped conductor (quartz crystal) in which the conical tip is designed to reflect the light to a phototransistor within the conductor (Figure D-2). As long as the conductor is in contact with air or vapor, the light beam is reflected within the crystal. However, when the conical tip comes in contact with a liquid, the light is refracted at the crystal face into the liquid, thereby preventing internal reflection which would normally be received by the phototransistor. When the light beam is interrupted, the phototransistor will emit a signal. This signal can be used to activate a secondary level control device.

Advantages and Disadvantages

Infrared sensors are very sensitive. They will also function in virtually any type of liquid, and are safe for use in explosive or flamable environments.

Disadvantages include fouling of the system by coatings which may collect on the tip of the conductor causing a false reading. Infrared sensors are also relatively expensive and are not considered to be very durable.

Range of Operation

When mounted in a fixed position, these devices are limited to high/low level sensing, but can be adapted to a movable level gauge for continuous level detection. Infrared sensors will operate in various types of liquids regardless of color, viscosity, density, dielectrics, or conductivity.

Specifications

Costs: \$450 - \$600

Accuracy: very good with sensitivities of ±1mm

References: Cheremisinoff, 1981
Liptak and Venczel, 1982

D.11 RESISTANCE TAPES

Principle of Operation

Resistance tapes have a helical resistance element wound in close proximity to a contact strip. Both are protected by a flexible, corrosion resistant sheath which acts as a pressure diaphragm (Figure D-3). The unit operates by detecting hydraulic pressure which causes the two elements (the helical coil and the contact strip) to come into contact. As the liquid level changes, the increased hydraulic head compresses the protective sheath, forcing the elements together. A pressure change of 0.2 psi is required to activate the tape. When the two elements touch, that portion of the tape shorts-out. The point of the short registers the liquid level.

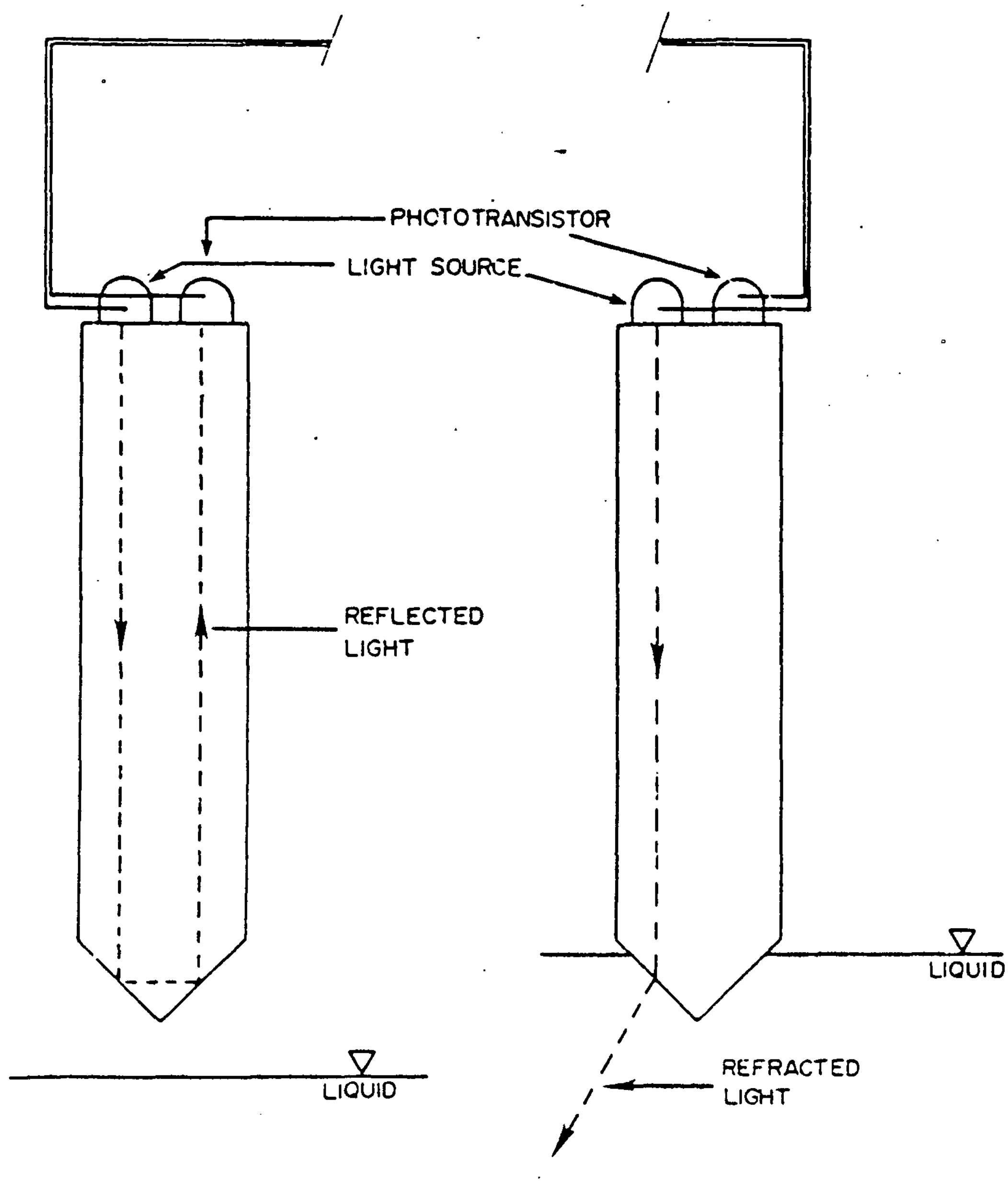
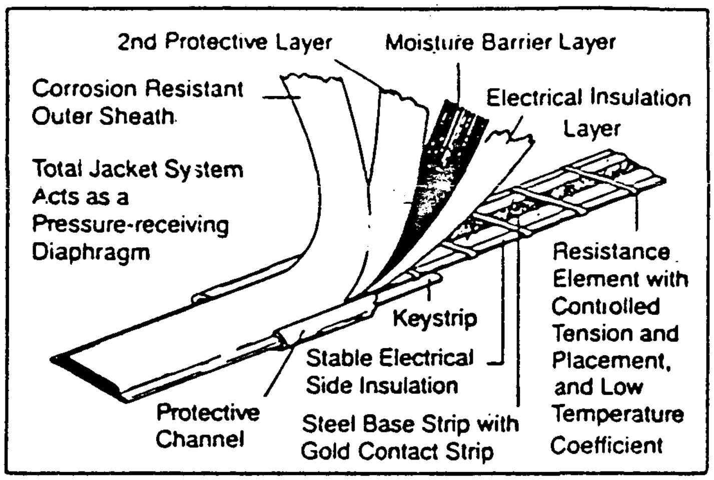


FIGURE D-2. INFRARED LIQUID LEVEL SENSOR



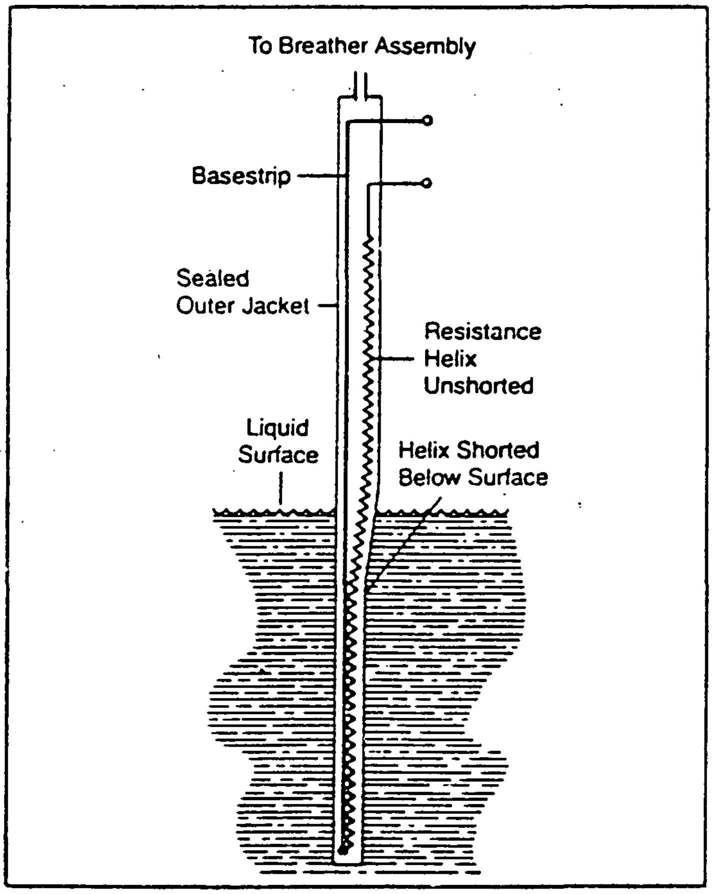


FIGURE D-3. RESISTANCE TAPE LEVEL SENSOR (METRITAPE, INC.).

Since a minimum pressure is required to activate the system, the upper most contact between the elements is some distance below the actual liquid surface. This distance is proportional to the density of the liquid, and the tape must be calibrated accordingly.

Advantages and Disadvantages

Advantages include the absence of moving parts and ease of installation and maintenance. Most applications are inexpensive and can be installed in hostile environments. They require only a micro-electrical current to operate and are safe to install in areas near explosive or ignitible materials. Since pressure is required to activate the unit, coating the tape will not result in fouling any contacts. Tapes can be manufactured to virtually any length to continually monitor liquid level.

Disadvantages include the need to calibrate the tape to the density of the liquid being measured and the need to maintain internal sheath pressure at the same pressure as that of the external environment.

Range of Operation

Resistance tapes can be manufactured to virtually any length up to 100 feet, and have the ability to measure levels of solids, slurries, and numerous liquids in clean and hostile environments. Some tapes also have the capability of continuously monitoring temperature (-15° C to +82° C) in addition to monitoring liquid level. Resistance tapes are suitable for use in closed or atmospheric environments.

Specifications

Costs: dependent on length and level only or level/temperature specifications; $450 - $1,300

Accuracy: resolution of ±1/8 inch for compensating tapes

References: Cheremisinoff, 1981
Hall, 1978
Liptak and Venczel, 1982

D.12 THERMAL SENSORS

Principle of Operation

Thermal sensors operate by detecting temperature and thermal conductivity differences between a liquid and vapor phase. The thermal probe consists of a resistant heating element which is monitored for temperature changes. As the probe is lowered into a liquid, the thermal conductivity of the liquid "cools" the probe by absorbing heat. When the thermal sensor is exposed to a vapor phase, the heating element warms the probe since the vapor's thermal conductivity is incapable of conducting a significant amount of heat away from the sensor. The heating and cooling of the probe is detected by a temperature sensitive relay which is capable of activating a secondary level control system.

Advantages and Disadvantages

Advantages include the ability to detect small changes in liquid level, ease of operation, and no moving parts.

A major disadvantages is that thermal sensors can not be employed in situations where process liquids can coat the probe.

Range of Operation

Typically, thermal sensors are used for point-level monitoring of critical liquid levels in materials where the temperature characteristics of the liquid do not vary widely. With the proper protective coating, these types of sensors can be employed in virtually any situation.

Specifications

Cost: $200 to $750

Accuracy: ±1/4 inch

References: Britz et al., 1982
Liptak and Venczel, 1982
Reason, 1984

D.13 ULTRASONIC DETECTORS

Principle of Operation

Ultrasonic level devices use sound waves, generally 20 kHz or above, to detect the liquid surface. An oscillating circuit within the device transmits the ultrasonic waves. The ultrasonic waves will either be dampened by the liquid or reflected off the liquid surface and used for the determination of the liquid level. The unit may be positioned at a desired level above the impoundment bottom for point-level detection. It may also be mounted above the impoundment for continuous level detection and monitoring. The unit is usually best situated for use with clean liquids, and may be employed for the detection of liquid-liquid interface.

Several types of ultrasonic devices are available. Basically, the units may be divided into dampened sensors, on-off transmitters and echometer types. Dampened sensors vibrate at their resonance frequency as long as the sensor face is not in contact with the liquid. When the liquid rises and comes in contact with the sensor, the vibration is dampened out and the level control action is activated. On-off transmitters contain a transmitter and receiver which generate and receive ultrasonic pulses. As the pulse beam is interrupted with the rise of the liquid, the level control action is carried out. The echometer type level detector operates using a burst of ultrasonic energy emitted by the unit. The sound waves are reflected off the top of the liquid surface and the return echo is detected by a receiver in the unit. The time required for sound waves to travel from transmitter to receiver is converted into liquid level based upon the velocity of sound.

Advantages and Disadvantages

Advantages of ultrasonic level detection devices include the absence of moving parts. The components of the device are sealed within the unit and require much less maintenance than a mechanical system. Some of the ultrasonic devices (echo) are also capable of continuous level monitoring without contacting the liquid. Also, ultrasonic systems are not dependent upon such properties of the liquid as density or specific gravity. The systems are easy to install and maintain, and are generally accurate.

Disadvantages of the system include problems with build-up on those units (dampened and on-off) which contact the liquid. This system should be used with clean liquids. If the unit contacts a waste which is viscous and accumulates on the probe, the device may respond with an inaccurate level reading. Units which do not contact the waste, such as the echometer type, will not have this tendency. Ultrasonic units are also affected by surface turbulence and foam. Many of the units require special filters or circuits to prevent false readings from random noise.

Range of Operation

Ultrasonic level detectors are used for point-level and continuous level monitoring of a wide variety of wastes. Those units which do not contact the waste are not affected by waste characteristics. Those units which do contact the waste are not recommended for corrosive wastes or wastes which may coat the sensor. Generally, all types of ultrasonics are applicable in storage and disposal impoundments containing corrosive or non-corrosive wastes.

Specifications

Cost: moderate to high; $200 and up for point-level indicators; $1800 and up for continuous indicators

Accuracy: up to $\pm 0.1\%$

References: Gillespie et al., 1982
Liptak and Venczel, 1982
Reason, 1984
Smith and Nagel, 1985
Sublett, 1976
Yearous, 1979

D.14 OTHER METHODS OF LEVEL DETECTION

This section addresses level detection systems which are not easily adaptable for use at hazardous waste surface impoundments. These systems are offered to illustrate the wide variety of other level detection systems available.

Antenna Level Sensors

These level sensors employ an antenna which is placed vertically or horizontally in the impoundment liquid. As the liquid rises and the antenna is covered, the signal transmitted from the antenna changes due to the changing dielectric constant in the transmitting medium (i.e., air to liquid). The signal received from the antenna is then related to liquid level depth.

Bubblers

Bubbler level monitoring devices use an air supply which is fed through a tube to the bottom of the impoundment. A gauge measures the pressure required to force air from the tube. Knowing the liquid density, the recorded pressure can then be converted to liquid depth. The system may be used for continuous level monitoring and may be operated manually or automatically.

Microwave Level Detectors

Microwave level detectors use an oscillating source which emits microwaves. These microwaves are then received by a detector. As the liquid level rises, the microwaves are attenuated within the liquid. The receiver determines liquid level from the microwave levels detected. These systems are usually expensive and difficult to install, and are not usually used for continuous level monitoring.

Optical Level Sensors

Optical level sensors use a beam of light to detect liquid level. A light source emits a beam of light, which is diffused into the liquid or reflected off the liquid surface. A receiver then detects the presence of liquid, and by judging the intensity of the light received determines the depth to liquid surface. Several systems are available including noncontact systems which may be used with corrosive wastes and those which are placed within the liquid.

Radiation Level Sensors

Radiation level sensors use a radiation source to transmit gamma rays which are received by a detector. Since the attenuation of gamma rays is dependent upon the density of the medium, the liquid level can be determined by the amount of radiation detected.

References: Barnik et al., 1978
Cheremisinoff, 1981
Gaeke and Smalley, 1975
Liptak and Venczel, 1982
Reason, 1984
Sandford, 1978
Williams, 1979
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