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PRELIMINARY REPORT
PROPOSED MEASURE TO MITIGATE THE POTENTIAL FOR LIQUEFACTION AT LACBWR PLANT SITE NEAR GENOA, WISCONSIN

DAIRYLAND POWER COOPERATIVE

INTRODUCTION

At the conclusion of the November 2 meeting, the Nuclear Regulatory Commission (NRC) directed Dairyland Power Cooperative (DPC) to propose measures to mitigate the postulated potential for liquefaction in the event that the LACBWR plant site experiences soil liquefaction in the top 40 feet due to a Safe Shutdown Earthquake (SSE) resulting in a ground surface acceleration of 0.12 g. Dames & Moore reviewed briefly the various alternatives available to accomplish this goal. The following discussion presents our preliminary conclusions regarding the feasibility of the various methods available for densifying and/or improving the foundation conditions to mitigate liquefaction potential.

METHODS OF DENSIFYING AND/OR IMPROVING SANDY SOILS

The following methods are generally used for densifying and/or improving cohesionless soils:

- Blasting
- Vibratory Probe
- Vibratory Rollers
- Compaction Piles
- Heavy Tamping (Dynamic Consolidation)
- Vibroflotation
- Grouting
- Displacement Grouting
- Vibro-Replacement Stone Columns (Gravel Drains)
- Freezing
- Dewatering

Each of the above methods was considered for its applicability to LACBWR plant site where an operating nuclear power plant exists. A number of them were eliminated immediately because of some serious limitations or other restrictions with respect to the LACBWR site.

BLASTING: Successive detonation of small explosive charges can be a rapid and economical means of densification of cohesionless soils. However, the shock waves and vibrations resulting from blasting may cause local liquefaction, nonuniform displacement and remolding of soil. Because of potential adverse effects on existing structures and pile foundations at the LACBWR plant site and the dangers associated with using explosives in a security sensitive area, the blasting technique was eliminated from further consideration.

VIBRATORY PROBE (TERRAPROBE): This method essentially consists of densifying a certain zone of the soil by inserting a vibrating probe to the desired depth. This method is best suited for an open undeveloped area. Settlements will be induced because of vibrations. Potential damage to underground pipelines could result. Also, it will not be possible to densify the soils under existing structures using normal working equipment and techniques. Therefore, the Terraprobe technique was considered unsuitable for further consideration for the LACBWR plant site.

VIBRATORY ROLLERS: Compaction of the soil is achieved by a self-propelled and towed vibratory roller. As this method is not effective at depths of roughly 6 feet below the ground surface, and the need to improve the soils at LACBWR plant site exists below 6 feet, this method was eliminated from further consideration.

COMPACTION PILES: By driving displacement piles at close spacing, densification of the soil can be accomplished. In addition to increasing the density (the increase in density may not be very significant unless the spacing is very close), the coefficient of lateral earth pressure increases and results in a considerable increase in cyclic shear strength. This is significant from the point of view of mitigation of the liquefaction problem at LACBWR site. Therefore, this method may be considered as an applicable option requiring further consideration. However, this method also suffers from the disadvantage that it is unsuitable where there are existing structures.

HEAVY TAMPING (DYNAMIC CONSOLIDATION): In this method, repeated impacts of a very heavy weight dropped from a height are used at predetermined spacings to achieve consolidation and densification under dynamic loadings. This method is obviously not suitable at sites with existing structures.

VIBROFLOTATION: In this method, densification is achieved by vibration of a "vibroflot" (a cylindrical penetrator about 400 mm in diameter and 2 meters long suspended by a crane, weighing about 2 tons and developing a horizontal centrifugal force at 1800 rpm). Granular backfill will be used to fill up the holes which will also be compacted by vibration. Again, this method cannot be used for densifying soils under structures.

GROUTING: This method of stabilization consists of either filling in the voids in the soil mass with cement or clay (particulate grouting), or injecting different chemicals which interact to solidify and strengthen the soil mass by the formation of a gel in their pores (chemical grouting), or stabilizing the soil mass by injecting highly viscous grout to displace the soil or by pressurized compaction (displacement grouting and compaction grouting). The displacement grouting and compaction grouting may result in pockets of saturated sand. The sand particle size at LACBWR site is not well suited for particulate grouting. Chemical grouting is feasible but at very high initial cost. An additional disadvantage is the extreme difficulty in reaching below the structures supported on numerous piles.

VIBRO-REPLACEMENT STONE COLUMNS: This method is similar to vibroflotation, except that the granular backfill used will be coarse gravel. The principle here is, in addition to densification, the overall effective permeability of the system will be increased so as to enable the dissipation of excess pore pressure as fast as it is generated during the earthquake. Like many other methods described earlier, this method can only be applicable to areas where there are no existing structures.

FREEZING: Freezing the ground and keeping it frozen for the lifetime of the structure could eliminate the potential for liquefaction. However, this solution is practical only for temporary rather than permanent conditions. The method also is relatively very expensive and may have the undesirable effect of freezing all the underground pipelines.

DEWATERING: The presence of water is what makes the sands susceptible to liquefaction. If the pore water is entirely removed by pumping the ground water and maintaining the water table at a lower level the potential for liquefaction is entirely eliminated above the water table. The potential for liquefaction is reduced under the water table because, when the water table is lowered, the effective stresses are increased and consequently the cyclic shear strength is increased.

After a preliminary investigation of the hydrogeologic conditions at the LACBWR site, the dewatering option was considered a feasible option and therefore, a preliminary design of the dewatering system was prepared for presentation to the NRC. After reviews and approval by NRC, further details of the dewatering system will be considered if necessary.

PRELIMINARY DESIGN OF THE DEWATERING SYSTEM

GENERAL

An area of approximately 200 by 160 feet in dimensions comprising of the reactor containment, the turbine building, the waste disposal building and the stack was considered for dewatering. The depth of the sandy soils suspected to be potentially liquefiable at the LACBWR site is 40 feet. The ground water level fluctuates between 8 to 12 feet below the existing plant grade. Figure 1 shows the effect of the depths to water table below the plant grade on the factors of safety against liquefaction potential at various depths. Figure 1 also shows that lowering the water table to about 20 feet below grade would increase the factor of safety from 1.39 to 1.80 at a depth of 30 feet and from 1.55 to 1.93 at a depth of 40 feet. The same information is presented in Table 1 in tabular form. Therefore, the dewatering system will be considered adequate if the water table can be lowered by a maximum of 12 feet from its existing level. However, the preliminary design is performed for a maximum draw down of 16 feet below the existing water table elevation that is, 25 feet below the plant grade. The final drawdown depth will be determined after appropriate field and laboratory permeability tests are done.

HYDROGEOLOGIC CONDITIONS AT LACBWR SITE

Figure 2 presents a schematic cross section of the subsoil conditions at the LACBWR site. During the floods of April 1965, evidence of direct hydraulic connection between   aquifer at the site and the adjacent river was observed. The manhole covers at the plant grade (approximate elevation of +639±) were forced open by the flood water where the water level at the river was also approximately +638±. The normal water level elevation of the river is +620±. The ground water level at the site fluctuates between +631 to +627. If the water table is lowered to +614± (25 feet below the plant grade), and maintained at that level, then there will be a permanent recharge from the river into the aquifer because of the direct hydraulic connection mentioned earlier.

The average permeability of the sands in the aquifer was estimated to be 80 ft/day using the information from grain size analyses. Some of the information provided by the DPC personnel regarding the quantities of water pumped out and the areas of excavation during the plant construction of the containment and the turbine building, the permeability values were back-calculated. The average resulting value of the permeability was approximately 150 ft/day. This higher value was used for the design of the dewatering system. However, pumping tests will be performed to verify our assumptions.

THE PROPOSED SYSTEM OF DEWATERING

Four different systems of dewatering were considered:

1. A perimeter well point system with a central pumping station;
2. A perimeter system of suction wells with a central pumping station;
3. A system of individual wells with individual pumps; and
4. Ranney wells with horizontal screens.

The perimeter well point system was considered unsuitable because of the close spacings (approximately 1-1/2 feet apart) mandated by the design calculations. The perimeter system of suction wells was also considered unsuitable because of practical limitations on pumping head. Ranney wells with horizontal screens require special construction techniques and therefore were not considered further. The proposed system is one of individual wells with individual pumps connected to a common discharge pipeline, as shown in Figure 3.

PRELIMINARY DESIGN DETAILS FOR THE PROPOSED SYSTEM

We have tentatively estimated that a total flow of 5000 gpm will have to be pumped continuously in order to achieve a draw down of approximately 15 feet at the center of the dewatering system. We have estimated that 5 individual wells, W-1 through W-5, each mounted with a 1000 gpm pump, as shown in Figure 3, will perform the required dewatering function. A sixth well, W-6, is provided as a backup for the dewatering system. The following are the design details of the wells and the pumps.

WELLS

Depth	100 feet
Minimum diameter of the hole	20 inches
Minimum diameter of casing	12 inches
Minimum diameter of screen	12 inches
Minimum length of screen	60 feet
Maximum length of blank casing	40 feet
Type of screen	Johnson Stainless Steel (or equivalent)
Width of slot	20-slot (0.020 inches)
Gravel pack	Proper size and quantities to fill in the annular space of the wells.

PUMPS

Moretrench American Corporation's pump No. 100TS or equivalent is proposed. This pump fits into a 12 inch casing and will pump 1000 gpm at 70 feet of head, and has a 20 horsepower submersible motor.

DISCHARGE PIPELINES

It is proposed that the dewatering system connected by two sections of 8 inch pipelines totalling 450 feet in length discharge into an 18 inch pipeline about 120 feet in length which picks up the combined flow and discharges into the river, as shown in Figure 3.

OTHER CONSIDERATIONS

Our preliminary evaluation is that the proposed dewatering system could mitigate liquefaction potential at the LACBWR site during Safe Shutdown Earthquake conditions.

There are other ramifications of dewatering, two were considered in this study. The first is the settlement resulting from increased effective stresses; the second is the down drag on the piles resulting from the settlement. Our preliminary calculations show that the settlement resulting from dewatering of a limited area is about a quarter of an inch. The dewatered area is expected to experience this settlement uniformly and in our opinion will not adversely affect the facilities at the site.

The down drag effects on the piles as a result of the settlement is expected to increase the load carried by the piles. Our preliminary calculations indicate that the increase of vertical load on piles is small. This increase, in our opinion, is not large enough to cause any concern on the safety of the foundations at the LACBWR site. Further detailed calculations will be made to verify our preliminary findings.

Table - 1
Effects of Depths to Water Table Below Plant Grade
On Factors of Safety Against Liquefaction (a_{max} = 0.12 g)

Depth Below Grade (ft)	τ_{avg} (PSF)	∇=0 τ (PSF)	∇=0 F.S.	∇=10 τ (PSF)	∇=10 F.S.	∇=20 τ (PSF)	∇=20 F.S.	∇=30 τ (PSF)	∇=30 F.S.	∇=40 τ (PSF)	∇=40 F.S.
10	86	75	0.87	-	NL	-	NL	-	NL	-	NL
20	163	150	0.92	240	1.47	-	NL	-	NL	-	NL
30	233	230	0.99	385	1.59	440	1.89	-	NL	-	NL
40	290	340	1.17	450	1.55	560	1.93	680	2.34	-	NL

τ_{avg} = average cyclic shear stress

τ = cyclic shear strength

∇ = depth to water table (ft)

NL = no liquefaction

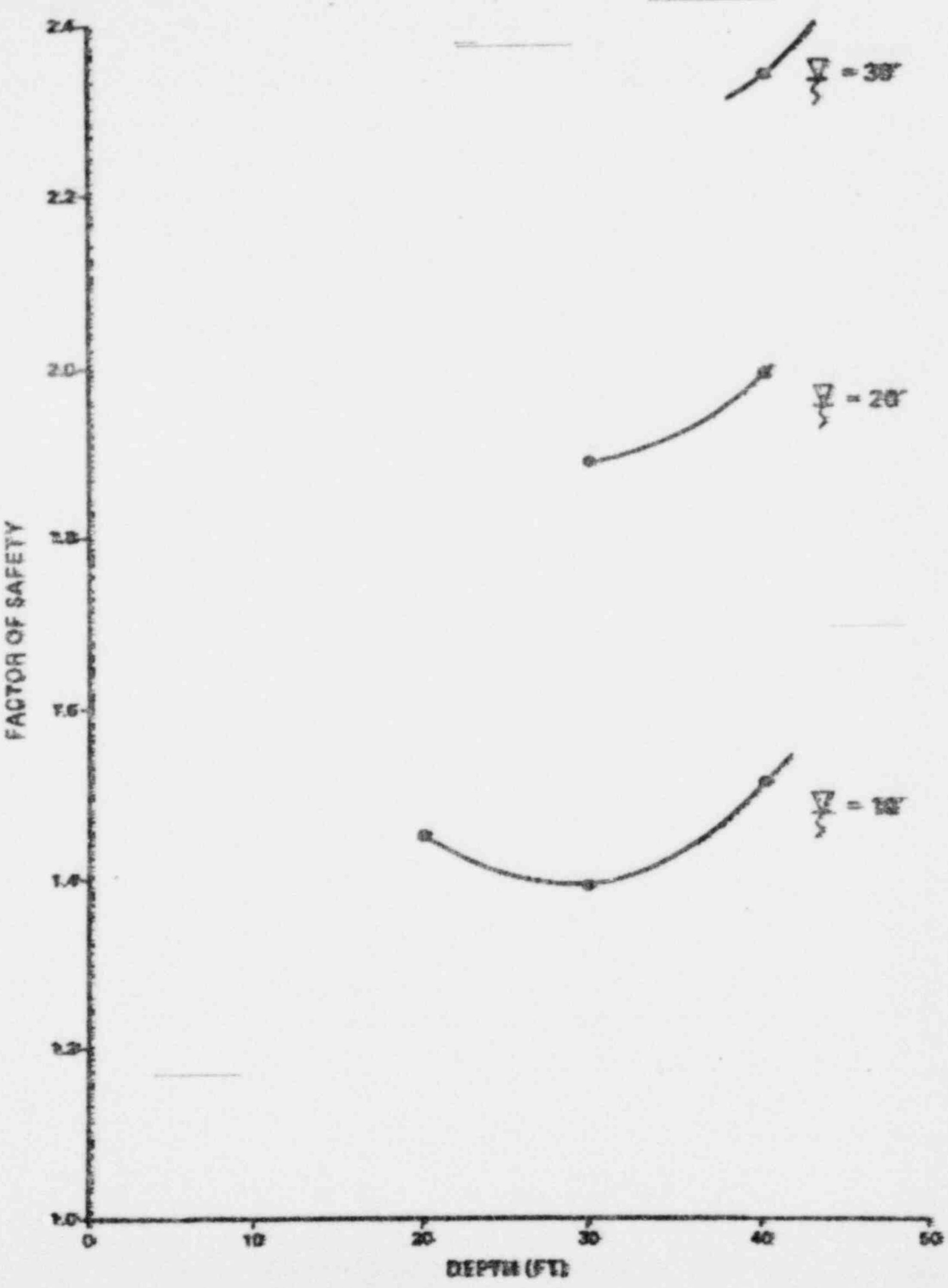

FIGURE 1

EFFECT OF DEPTHS TO WATER TABLE BELOW PLANT GRADE ON FACTORS OF SAFETY AGAINST LIQUEFACTION

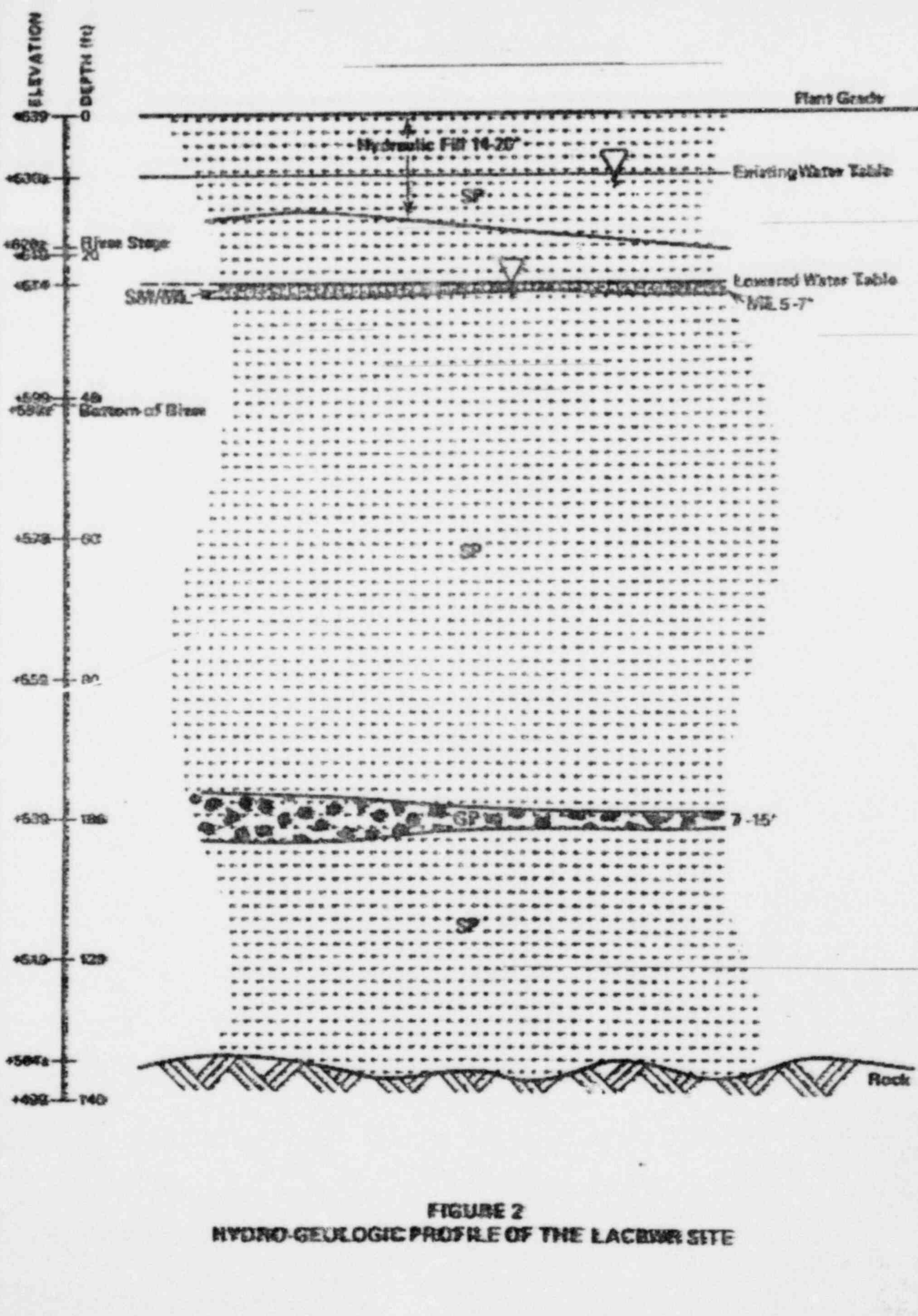

FIGURE 2
HYDRO-GEOLOGIC PROFILE OF THE LACBWR SITE

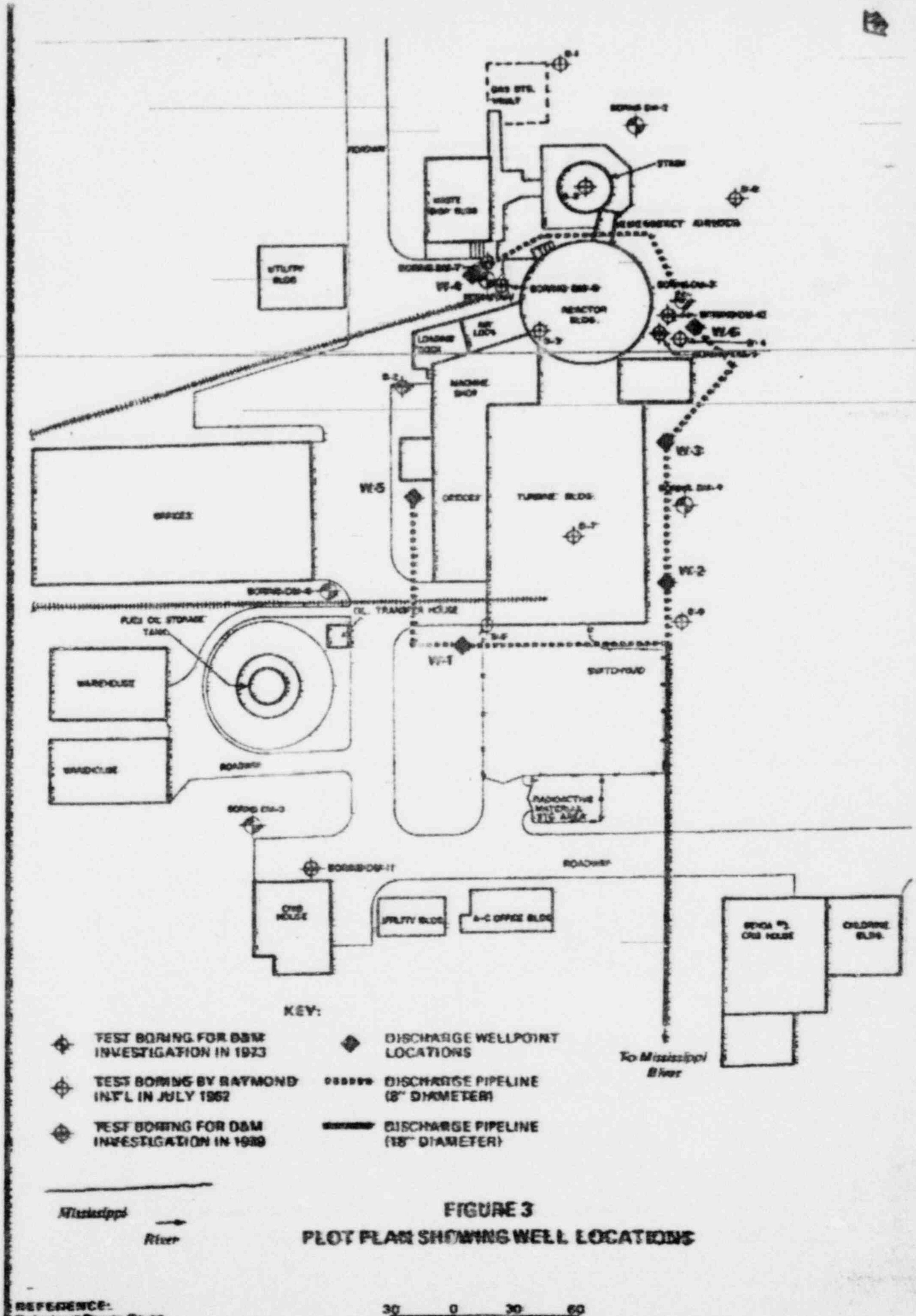

FIGURE 3
PLOT PLAN SHOWING WELL LOCATIONS

REFERENCE:
Dairyland Power Co-op
Drawing LB-22, 10/2/69
Raymond Project CB-1354-C

DAMES & MOORE