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Managing Water in the West

Water Operation and Maintenance Bulletin

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This *Water Operation and Maintenance Bulletin* is published quarterly for the benefit of water supply system operators. Its principal purpose is to serve as a medium to exchange information for use by Bureau of Reclamation personnel and water user groups in operating and maintaining project facilities.

The *Water Operation and Maintenance Bulletin* and subject index may be accessed on the Internet at: <**http://www.usbr.gov/pmts/infrastructure/inspection/waterbulletin**>.

Although every attempt is made to ensure high quality and accurate information, the Bureau of Reclamation cannot warrant nor be responsible for the use or misuse of information that is furnished in this bulletin.

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Stressing about the Summer Heat?

by Steven D. Engleman, CIH[1]

Now that we are experiencing the heat of summer in Colorado, it is important to be aware of the effects of that heat on our bodies and health. Heat stress can come from a variety of sources and can affect the body in various ways. Temperature, humidity, radiant heat, and air velocity are four environmental factors that affect the amount of heat stress an individual encounters. The body reacts to high external temperatures by circulating blood to the skin, which increases epidermal temperature and allows the body to give off excess heat through the skin. But, if muscles are being used for physical labor, less blood is available to flow to the skin and release the heat.

Sweating is another method the body uses to maintain a stable internal body temperature. However, sweating is effective only if the humidity level is low enough to permit evaporation and if lost fluids and salts are adequately replaced. Fortunately, in Colorado, low humidity helps us in this respect.

If the body cannot dispose of excess heat, it will store it. When this happens, the body's core temperature raises, the heart rate increases, and, if necessary precautions are not taken, a number of traumatic events can occur. Individuals may not be able to concentrate, have difficulty focusing on tasks, become irritable or sick, and may lose their desire to drink. Once these symptoms occur, the next stage most often is fainting, but even death is possible if the person is not removed from the heat-induced situation.

Electrolytes can help protect employees from heat-induced stress. Under ideal situations, electrolytes flow through muscle cells to keep them functioning normally. However, in heat stress situations, these precious minerals are lost through perspiration or other forms of dehydration, which depletes muscle cells of fluids and weakens muscle tissue. Drinking water can keep the body hydrated, but drinking water alone does not quickly replace the electrolytes needed to keep the body functioning properly. Water still reigns as nature's perfect drink, but it takes a back seat to electrolyte replacement beverages in high-heat situations. In fact, the rate of absorption of electrolyte replacement products, when compared with water, is 98 percent faster in the first minute. When working against heat-related ailments, time can sometimes be the most critical factor in keeping safe and protected.

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[1] Industrial Hygienist, Reclamation Safety and Health Office, Bureau of Reclamation, Technical Service Center, Denver, Colorado; (303) 445-2696.

Know the warning signs of heat-related ailments to help protect yourself and others. There are three categories of heat-related ailments: heat cramps, heat exhaustion, and heat stroke.

- ***Heat cramps*** are muscle spasms caused by heavy sweating. They normally affect the arms, legs, or stomach and frequently don't occur until after work, at night, or when relaxing. To prevent heat cramps, it has been advised that one should drink electrolyte solutions during the day and eat fruit such as bananas.

- ***Heat exhaustion*** occurs when surface blood vessels and capillaries that originally enlarge to cool the blood collapse from loss of body fluids and necessary minerals. Symptoms include headache, cool moist skin, weak and rapid pulse, and low blood pressure.

- ***Heat stroke*** is a life-threatening illness that occurs when the body has exhausted its supply of water and salt, and the victim's body temperature rises dangerously. It can be mistaken for a heart attack, so co-workers must be able to recognize symptoms:

    - Elevated body temperature
    - No sweating
    - Dry skin that is red or flushed
    - Rapid pulse
    - Breathing difficulty
    - High blood pressure
    - Dizziness
    - Headache
    - Nausea
    - Confusion

On average, 175 Americans die of heat-related injuries each year. In addition, the costs associated with lost time due to workplace accidents are usually overwhelming. According to 1998 statistics from the National Safety Council, the cost per worker for a disabling lost-time injury averages about $28,000—this includes both direct and hidden costs. Direct costs include medical and employee compensation costs. Hidden costs can range from time lost from work to loss in earning power; economic loss to the family of the injured employee; lost time by fellow workers; loss of efficiency due to the breakup of the crew; lost time by supervision; the cost of training new employees; damage to tools and equipment; the time damaged equipment is out of service; spoiled work; loss of production; spoilage from fire, water, chemicals, etc.; failure to fill orders; and increased overhead cost while the work was disrupted.

Managers should know the symptoms and take quick action when heat-related problems occur. Because heat stress illnesses manifest themselves on a continuum of severity where heat cramps may lead to heat exhaustion or heat stroke, it is imperative that each occurrence be seriously and cautiously addressed. When persons are exhibiting symptoms of heat stress, it is best to seek advice on subsequent actions to be taken from a medical practitioner.

The Occupational Safety and Health Administration offers tips for workers and employers to follow when persons are working in hot environments:

1. Drink cool water. Someone working in a hot environment should drink cool water in small amounts frequently—one cup every 20 minutes. Employers should make water and/or electrolyte-replacement beverages available. Avoid alcohol, coffee, tea, and soft drinks with caffeine, which cause dehydration.

2. Dress appropriately. Wear lightweight, loose-fitting clothing and change clothing if it becomes completely saturated. Use sunscreen and wear a hat when working outdoors.

3. Work in ventilated areas. All workplaces should have good general ventilation, as well as spot cooling in work areas of high heat production. Good air flow increases evaporation of sweat, which cools the skin.

4. Supervisors should assess the work force and environmental conditions in order to assign tasks appropriately during high heat conditions. Under extreme conditions, supervisors should assign a lighter workload and longer rest periods during the days of intense heat. Short, frequent work/rest cycles are best. Schedule heavy work during cooler times of the day.

5. Ask workers how they're feeling. Supervisors should monitor workplace temperature and humidity and check workers' responses to heat at least hourly. Allow a large margin of safety, be alert to early signs of heat-related illness, and allow workers to stop for a rest break if they become uncomfortable.

6. Know the signs and take prompt action. Employees and employers should learn to spot the signs of heat stroke, which can be fatal. Get emergency medical attention immediately if someone exhibits confusion, loss of consciousness, flushed face, hot and dry skin, or has stopped sweating.

7. Train first aid workers. First aid workers should be able to recognize and treat the signs of heat stress, heat exhaustion, heat cramps, and other heat-related illness. Be sure all workers know who is trained to give first aid.

8. Reduce work for anyone at risk. Employers should use common sense when determining fitness for work in hot environments. Lack of acclimatization, age, obesity, poor conditioning, pregnancy, inadequate rest, previous heat injuries, certain medical conditions, and medications are some factors that increase someone's susceptibility to heat stress.

9. Check with your doctor. Certain medical conditions, such as heart conditions and diabetes, and some medications can increase the risk of injury from heat exposure. Employees who have medical conditions or take medication should ask their doctors before working in hot environments.

10. Watch out for other hazards. Use common sense and monitor other environmental hazards that often accompany hot weather, such as smog and ozone.

For those who may find themselves wondering what may be done for a person exhibiting symptoms of heat cramps (dehydration), it is generally accepted that helping a person to a cooler place in order to rest and recuperate, providing cool water for "sipping," and an application of pressure to the effected areas of the body provide relief in most cases. However, there are situations in which the severity of the cramping may require transport to a medical facility for fluid replacement therapy.

Initial emergency care for heat exhaustion also suggests that the person be assisted to a cool place. At this stage, it is recommended that as much clothing be removed as the conditions allow and that water be provided for sipping. In addition, fanning and misting can be used to accelerate cooling, but caution should be taken to not over-cool the individual, as this may lead to shock. Ultimately, the victim should be transported to a medical facility for observation.

When heat stroke occurs, remember that it is a true "emergency," and transportation to a medical facility must not be delayed. In providing first aid during transport, every effort should be made to cool the individual—this includes removing as much clothing as is feasible. Gradually lower the person's body temperature by means that might include fanning, soaking clothing in cool water, misting, or placing cold packs around the neck, under the arms, and ankles. In addition, verify that the heat stroke victim's airway is open.

Heat stress, when it progresses to heat stroke, can be fatal. Treat it with care.

Introduction of a New Materials Engineer in the Technical Service Center

The Technical Service Center (TSC) is happy to introduce a new addition to their staff. His name is **Roger Turcotte**, and he is the new Corrosion Engineer in town. Roger will be taking on the responsibilities of Tom Johnson, who left last year to accept a position with the Bureau of Land Management. Roger will be working closely with Greg Myers on cathodic protection and other corrosion-related issues. You may have seen Roger's contribution, a light-hearted article on the heavy subject of stainless steel written under the pen name Rusty H. Fingers and entitled, ""Dear Rusty" – Answers to Corrosion Inquiries," in the latest issue of *Reclamation Managing Water in the West*.

Roger comes to the Bureau of Reclamation from the private sector, having worked in various areas of Corrosion/Materials Engineering for about 25 years. He is a licensed professional engineer, holds all three ANSI/API tank, vessel, and piping inspector certifications, and is a NACE certified Corrosion Protection Tester. Roger has a B.S. in Chemical Engineering from the University of Maine and an M.S. in Ocean Engineering from the University of Rhode Island. He is active in the National Association of Corrosion Engineers, Intl. (NACE), having been a former chairman and trustee with the Greater Boston Section, and is a member of the American Society for Metals, Intl. (ASM) and of the American Institute of Chemical Engineers (AIChE).

Roger's responsibilities include:

- Design of cathodic protection systems
- Field inspection of corrosion damage and of cathodic protection systems
- Review of contractor's designs and submittals
- Corrosion testing, both lab and field
- Selecting materials of construction
- Failure analysis
- Corrosion R&D

Please feel free to approach Roger with your corrosion/materials issues. You can come speak with him in person in the Materials Engineering and Research Laboratory (D-8180) of the TSC, or he can be reached at (303) 445-2383 or online at rturcotte@do.usbr.gov.

Engine-Generator Maintenance, Inspection, and Testing

The purpose of this document is to clarify Bureau of Reclamation (Reclamation) practices for non-portable engine-generator maintenance, inspection, and testing.

Executive Summary

Engine-generators are critical systems at powerplants, dams, and other water-related facilities. They must be maintained and tested regularly to ensure they will perform as expected. Manufacturer and National Fire Protection Association (NFPA) standards should be followed.

Background

Engine-generators provide essential power to supply critical loads in the event of loss of normal power source. Spillway or outlet gates/valves may need to be operated for water release purposes with engine-generator power. Powerplant critical loads such as sump pumps, fire pumps, and battery chargers also are dependent on reliable power. Engine-generators also may be used to power unit auxiliaries and the generator excitation system for blackstart generators assigned to restore the power system after a blackout.

Existing Reclamation guidance documents for operation, maintenance, and testing of these engine-generators are incomplete. Although facilities are required to demonstrate successful operation of engine-generators (e.g., for emergency gate operation) during on-site facility reviews, there is no Reclamation guidance for preventive maintenance, inspection, or testing in Facilities Instructions, Standards, and Techniques (FIST) volumes. Many facilities rely on the manufacturer's maintenance recommendations.

Discussion

Conscientious, proactive maintenance and testing of engine-generators is required to ensure they will perform as expected. Existing standards such as NFPA define recommended practices for engine-generator maintenance and testing. These eventually will be addressed by Reclamation FIST volumes, but guidance is needed in the interim.

Conclusions

Engine-generator maintenance and testing guidance are provided in this bulletin and will be included in future revisions to FIST volumes.

Recommendations

Emergency power supply systems (EPSS) comprising engine-generators and associated equipment such as automatic transfer switches must be maintained, inspected, and tested in accordance with manufacturer's recommendations and NFPA 110, Standard for Emergency and Standby Power Systems (2002). Refer to NFPA 110, Annex A, Figure A.8.3.1 (a) for a complete maintenance schedule. Key inspection and testing requirements are shown in the following table:

Key NFPA Requirements for Inspection and Testing of Standby Power System

Component	Requirement	Frequency	NFPA 110 Reference
All EPSS Components	Inspect	Weekly	8.4.1
EPSS System	Operated at available load for assigned class duration or minimum of 4 hours	At least once every 36–48 months	8.4.8 & 4.2 and table 4.1(a)
Generator Sets	Exercised for a minimum of 30 minutes[1] (including automatic cold start) by: (1) Running at operating temperature conditions and at not less than 30% of the nameplate kW rating; or (2) Loading that maintains the minimum exhaust gas temperatures as recommended by the manufacturer	At least monthly[2]	8.4.2
Generator Set Battery	Inspected and maintained in full compliance with manufacturer's recommendations	Weekly	8.3.6
Transfer Switch	Operated electrically, both directions	Monthly	8.4.5
Circuit Breakers	Exercised manually	Annually	8.4.6

[1] Load exercising at normal operating temperature is important because it prevents accumulation of carbon particles, unburned fuel, lube oil, condensed water and acids in the exhaust system, and other engine problems that can occur with unloaded exercising.

[2] Note: In addition, per manufacturers' recommendations, many facilities start and run the engine-generator weekly.

See NFPA 110 and POM-400 form for complete inspection, testing, and maintenance requirements.

Testing and maintenance records for engine-generators should be maintained on site.

Engine-generator maintenance, inspection, and testing Power O&M Form (POM-400) is available electronically at <http://intranet.usbr.gov/forms/>. A Word version of this form is available from D-8450, phone (303) 445-2300. This form may be altered to develop site-specific checksheets. Maintenance, inspection, and testing should be conducted using the following definitions:

- Level 1EPSS maintenance, inspection, and testing are required when failure of the emergency power supply system could result in the loss of human life or serious injuries (NFPA 110, Section 4.4.1). This includes engine-generators required for water release purposes (via gates/valves) and for support of plant systems related to personnel safety. Level 1 EPSS maintenance, inspection, and testing also applies to EPSS at plants essential to power system blackstart restoration plans and to plants where significant damage would occur upon failure of the emergency power supply system.

- Level 2 EPSS maintenance, inspection, and testing are applicable when failure of the emergency power supply system is less critical to human life and safety and when flexibility greater than Level 1 is permissible (NFPA 110, Section 4.4.2). Level 2 maintenance, inspection, and testing apply when the emergency power supply system is not essential for water release purposes (via gates/valves), when blackstart capability is not required, and when no significant damage to the plant would occur if the system failed.

Each facility with emergency power supply systems comprising engine-generators and associated equipment should tailor maintenance, inspection, and testing in accordance with this PEB, NFPA 110, and manufacturer’s instructions. These requirements may need to be adjusted locally for engine-generators that are inaccessible and not required to be in service due to location, weather, or seasonal operation.

Questions should be directed to Paul Price at (303) 445-2299.

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ENGINE GENERATOR OPERATION AND TESTING LOG

ENGINE GENERATOR OPERATION AND TESTING PROCEDURES SUMMARY (See Pages 2 thru 6)

Item Number	Function	Item Number	Function
1.	Perform maintenance per Pages 2 thru 4.	8.	Record initial oil pressure and battery-charging rate.
2.	Record running time meter reading at start and end of test.	9.	Record oil pressure, battery charging rate, and water or air temperature after 15 minutes running time
3.	Simulate normal power failure from a "cold start" by use of the test switch in the automatic transfer switch or by opening normal power supply to EPSS.	10.	Record prime mover and ac instruments, just prior to transfer.
4.	Observe and record time delay or start.	11.	Return test switch to normal or reestablish normal power supply after a minimum running time of 30 minutes under 30% load (or after 4 hours under 80% load).
5.	Record cranking time (terminated when engine starts).	12.	Record time delay on retransfer.
6.	Transfer load to EPS (30% monthly) (80% every three years)	13.	Record time delay on shutdown for units so equipped.
7.	Record ac voltage, frequency, amperage.	14.	Place unit in automatic operation mode.

ENGINE GENERATOR OPERATION AND TESTING LOG SUMMARY

		Performed by
		Date
	Items	Fill in Appropriate Readings, add comments on condition and maintenance completed.
1.	Maintenance completed Pages 2-4	
2.	Run Time Meter	
3.	Power fail test	
4.	Time Delay Start	
5.	Crank time	
6.	Transfer Switch	
7.	(a) ac volt	
	(b) Hz	
	(c) ac amp.	
8.	(a) Oil press.	
	(b) dc amp.	
9.	(a) Oil press.	
	(b) dc amp.	
	(c) W/A temp.	
10.	(a) Oil press.	
	(b) dc amp.	
	(c) W/A temp.	
	(d) ac volts	
	(e) Hz	
	(f) ac amp.	
11.	Restore normal	
12.	T/D retransfer	
13.	T/D stop	
14.	Auto mode	

Comments:

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ENGINE GENERATOR MAINTENANCE SCHEDULE

- Level 1EPSS maintenance, inspection, and testing is required where failure of the emergency power supply system could result in the loss of human life or serious injuries (NFPA 110, Section 4.4.1). This includes engine-generators required for Dam Safety purposes and for support of plant systems related to personnel safety. Level 1 EPSS maintenance, inspection, and testing also applies to EPSS at plants essential to power-system blackstart restoration plants and to plants where significant damage would occur upon failure of the emergency power supply system.
- Level 2 EPSS maintenance, inspection, and testing is applicable where failure of the emergency power supply system is less critical to human life and safety and where greater flexibility than Level 1 is permissible (NFPA 110, Section 4.4.2). Level 2 maintenance, inspection, and testing applies where the emergency power supply system is not essential for Dam Safety purposes, where blackstart capability is not required, and where no significant damage to the plant would occur if the system fails.

	Procedure X – Action R – Replace, if needed						Frequency W = Weekly M = Monthly Q = Quarterly	S = Semiannually A = Annually Nos. indicate hours
Component (as applicable)	Check if complete	Visual Inspection	Check	Change	Clean	Test	Level 1	Level 2
1. Fuel								
(a) Main supply tank level			X				W	M
(b) Day tank level		X	X				W	M
(c) Day tank float switch		X				X	W	Q
(d) Supply or transfer pump operation		X				X	W	Q
(e) Solenoid valve operation		X				X	W	Q
(f) Strainer, filter, dirt leg, or combination					X		Q	Q
(g) Water in system			X		X		W	Q
(h) Flexible hose and connectors		X		R			W	M
(i) Tank vents and overflow piping unobstructed			X			X	A	A
(j) Piping		X					A	A
(k) Gasoline in main tank (when used) or diesel fuel				R			A*	A*
2. Lubrication System								
(a) Oil level		X	X				W	M
(b) Oil change				R			50 hours or A	50 hours or A
(c) Oil filter(s)				X			50 hours or A	50 hours or A
(d) Lube oil heater			X				W	M
(e) Crankcase breather		X		R	X		Q	S
3. Cooling System								
(a) Level		X	X				W	M
(b) Antifreeze protection level						X	S	A
(c) Antifreeze				X			A	A
(d) Adequate cooling water to heat exchanger			X				W	M
(e) Rod out heat exchanger					X		A	A
(f) Adequate fresh air through radiator			X				W	M
(g) Clean exterior of radiator					X		A	A
(h) Fan and alternator belt		X	X				M	Q
(i) Water pump(s)		X					W	Q
(j) Condition of flexible hoses and connection		X	X				W	M
(k) Jacket water heater			X				W	M
(l) Inspect duct work, clean louvers		X	X	X			A	A
(m) Louver motors and controls		X			X	X	A	A
4. Exhaust System								
(a) Leakage		X	X				W	M
(b) Drain condensate trap			X				W	M

* Maximum time between fuel renewals – more frequent replacement may be necessary

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ENGINE GENERATOR MAINTENANCE SCHEDULE (con't)

	Procedure X – Action R – Replace, if needed						Frequency W = Weekly M = Monthly Q = Quarterly	S = Semiannually A = Annually Nos. indicate hours
Component (as applicable).	Check if complete	Visual Inspection	Check	Change	Clean	Test	Level 1	Level 2
(c) Insulation and fire hazards		X					Q	Q
(d) Excessive backpressure						X	A	A
(e) Exhaust system hangers and supports		X					A	A
(f) Flexible exhaust section		X					S	S
5. Battery System								
(a) Electrolyte level			X				W	M
(b) Terminals clean and tight		X	X				Q	Q
(c) Remove corrosion, case exterior clean and dry		X			X		M	M
(d) Specific gravity or state of charge						X	M	M
(e) Charger and charge rate		X					M	M
(f) Equalize charge			X				M	M
6. Electrical system								
(a) General inspection		X					W	M
(b) Tighten control and power wiring connections			X				A	A
(c) Wire chafing where subject to movement		X	X				Q	S
(d) Operation of safeties and alarms			X			X	S	S
(e) Boxes, panels, and cabinets					X		S	S
(f) Circuit breakers, fuses Note: Operate circuit breakers by hand manually.		X	X	R	X	X	A	A
(g) Transfer switch main contacts		X			X		A	A
(h) Operate transfer switch electrically in both directions using the automatic control system		X	X		X	X	M	M
(i) Calibration of voltage-sensing relays/devices			X			X	A	A
(j) Wire insulation breakdown						X	3 years or 500 hours	5 years or 500 hours
7. Engine/Generator								
(a) General inspection		X					W	M
(b) Service air cleaner				X	X		S	S
(c) Governor oil level and linkage		X	X				M	M
(d) Governor oil				X			A	A
(e) Ignition system – plugs, points, coil, cap, rotor, secondary wire insulation		X	X	R	X	X	A	A
(f) Choke setting and carburetor adjustment			X				S	S
(g) Injector pump and injectors for flow rate pressure, and/or spray pattern						X	A	A
(h) Run generator loaded minimum of 30% nameplate rating monthly for 30 min.						X	M/30 Min.	M/30 Min.
(i) Run generator loaded minimum of 80% nameplate rating every 3 years for 4 hours						X	3 years/4 hours	3 years/4 hours

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ENGINE GENERATOR MAINTENANCE SCHEDULE (con't)

	Procedure X – Action R – Replace, if needed						Frequency W = Weekly S = Semiannually M = Monthly A = Annually Q = Quarterly Nos. indicate hours	
Component (as applicable).	Areas all complete	Visual Inspection	Check	Change	Clean	Test	Level 1	Level 2
(j) Valve clearance						X	3 years or 500 hours	3 years or 500 hours
(k) Torque bolts						X	3 years or 500 hours	3 years or 500 hours
8. Generator								
(a) Brush length appearance, free to move in holder		X	X		X		S	S
(b) Commutator and slip rings		X			X		A	A
(c) Rotor and stator		X			X		A	A
(d) Bearing(s)		X		R			A	A
(e) Bearing grease			X	R			A	A
(f) Exciter		X	X		X		A	A
(g) Voltage regulator		X	X		X		A	A
(h) Measure and record resistance readings of windings with insulation tester (Megger)						X	A	A
9. (a) General condition of EPSS, any unusual condition of vibration, leakage, noise, temperature, or deterioration		X			X		W	M
(b) Service room or housing housekeeping		X			X		W	M
10. Restore system to automatic operation condition		X					W	M

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ENGINE GENERATOR MAINTENANCE LOG
RECORD RESULTS OF PAGES 1-4

Performed by

Frequency
W - Weekly
M – Monthly
Q – Quarterly
S - Semiannually
A – Annually
Nos. indicate hours

Item No.	Service Frequency Level 1	Service Frequency Level 2	Date / Fill in Appropriate Readings, add comments on conditions and maintenance completed.
1. (a)	W	M	
(b)	W	M	
(c)	W	Q	
(d)	W	Q	
(e)	W	Q	
(f)	Q	Q	
(g)	W	Q	
(h)	W	M	
(i)	A	A	
(j)	A	A	
(k)	A	A	
2. (a)	W	M	
(b)	50 or A	50 or A	
(c)	50 or A	50 or A	
(d)	W	M	
(e)	Q	S	
3. (a)	W	M	
(b)	S	A	
(c)	A	A	
(d)	W	M	
(e)	A	A	
(f)	W	M	
(g)	A	A	
(h)	M	Q	
(i)	W	Q	
(j)	W	M	
(k)	W	M	
(l)	A	A	
(m)	A	A	
4. (a)	W	M	
(b)	W	M	
(c)	Q	Q	
(d)	A	A	
(e)	A	A	
(f)	S	S	
5. (a)	W	M	
(b)	Q	Q	

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ENGINE GENERATOR MAINTENANCE LOG *(continued)*
RECORD RESULTS OF PAGE 1-4

Performed by

Frequency
W - Weekly S - Semiannually
M – Monthly A – Annually
Q – Quarterly Nos. indicate hours

Item No.	Service Frequency Level 1	Level 2	Date / Fill in Appropriate Readings, add comments on conditions and maintenance completed.
(c)	M	M	
(d)	M	M	
(e)	M	M	
(f)	M	M	
6. (a)	W	M	
(b)	A	A	
(c)	Q	S	
(d)	S	S	
(e)	S	S	
(f)	A	A	
(g)	A	A	
(h)	M	M	
(i)	A	A	
(j)	3/500	5/500	
7. (a)	W	M	
(b)	S	S	
(c)	M	M	
(d)	A	A	
(e)	A	A	
(f)	S	S	
(g)	A	A	
(h)	M/30 min.	M/30 min.	
(i)	3/4	3/4	
(j)	3/500	3/500	
(k)	3/500	3/500	
8. (a)	S	S	
(b)	A	A	
(c)	A	A	
(d)	A	A	
(e)	A	A	
(f)	A	A	
(g)	A	A	
(h)	A	A	
9. (a)	W	M	
(b)	W	M	
10.	W	M	

Drainage of Irrigated Lands

by Roger Burnett, P.E.[1]

The science and engineering of drainage have come a long way in the last four decades. Today, drainage is out of the "put the drain here and see how it works" stage where it had been for so long. Although sound judgment is still essential to a good job, technical tools are now available to make drainage an engineering and economically feasible undertaking. This is fortunate because, except in rare instances, drainage is essential to sustained high productivity under irrigation. This is the way nature made it, and man cannot change it.

Irrigated areas start with certain basic characteristics. There are given soils underlain by various substrata and geologic formations, and the area has a certain topography. There will be a wild plant community of some sort. Rain and snow fall more or less regularly, and under nature all these things have reached a balance. They stay that way until farmers come along. The farmers clear the land, level it, irrigate it, plant crops, try for high production, and put on more water than native plants require. What happens? Waterlogging or salinization, or both—they usually go hand in hand. These are drainage problems, which lead to a simple definition for drainage—the "removal of excess water and excess salt from agricultural lands."

Most of our discussion will deal with the complexities of drainage that are concerned with what happens beneath the surface—subsurface drainage. Surface drainage is important, but it is a natural process. Water runs downhill; it must be kept moving and not allowed to pond so the land will not get too wet. This is surface drainage. The other kind of drainage that is so essential, subsurface drainage, is a form of land maintenance. Dams, canals, pipelines, roads, and land must be maintained. Drainage is an important form of maintenance. With enough good drainage, even the poorest farmer cannot very well ruin land. With poor drainage, the best farmer cannot be successful. Sooner or later salts or groundwater, or both, will rise to the zone of the soil where the plants grow. This may take 2 or 20 years, sometimes longer.

Irrigation or drainage districts are basically concerned with the drainage of irrigated lands and sometimes with lands that are adversely impacted because of nearby irrigation. The principal objectives of districts should be to predict and

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prevent waterlogging and to keep salts and alkalies away from plants. They should try to avoid the necessity of having to reclaim waterlogged lands by not allowing them to become waterlogged in the first place.

In recent years, concern over the destruction of wetlands has changed the drainage planning process. With passage of the Food Security Act of 1986, designated wetlands cannot be drained without forfeiting eligibility for many farm programs. It, therefore, becomes doubly important to predict and treat drainage deficiencies before they manifest themselves as wetland environments.

The general feeling among people not closely associated with drainage problems has been that the problems do not start for many years after irrigation. Although there are exceptions, in most cases this has not been true. The problems sometimes develop slowly, but they begin soon after irrigation starts. Sometimes the causes are not readily apparent, and careful analysis is needed to locate them. Often new problems develop merely because of changes in cropping practices, like changing from alfalfa to beans. Sometimes new problems develop when farms change hands. Usually, however, assuming reasonably good farming operations and good water management by the irrigation district, the problems stem from basic natural land characteristics or faulty irrigation works.

Inadequate subsurface drainage adversely affects plants in two ways. In one way, the root zone becomes waterlogged and the plants literally drown. They cannot get needed oxygen. In the other way, the plants are poisoned or starved of nutrients and moisture by excessive salinity in the root zone. As the deep percolation from irrigation moves downward, it carries along dissolved salts that were in the irrigation water and it dissolves some of the residual salts in the soil. Also, the salinity of the moisture within the root zone is concentrated because the plants basically remove pure water and leave the dissolved salts behind. When this water reaches the groundwater body, it adds this salt load, and the groundwater becomes increasingly saline. More deep percolation results from each irrigation, and gradually the water table builds up toward the ground surface. Then, the phenomenon of capillarity becomes an important factor in the salinity problem.

Capillarity is the force that moves oil up into the wick of a lamp, against gravity, or ink into a blotter. Most people have seen some form of capillarity in a science laboratory. Perhaps they suspended a capillary tube in a liquid. The liquid rose in the tube above the level of the liquid, and the smaller the diameter of the capillary, the higher the water rose. The same thing happens in soil. If the groundwater is too near the surface, capillarity moves water upward into the root zone. As the plants take up and use the good water from irrigation stored in the capillary pores of the soil in the root zone, the salty groundwater moves upward through the chain of small capillary pore spaces in the soil to replace the good water. If displacement of the saltwater downward by good water from irrigation or rain does not occur soon enough, the salty water eventually reaches the surface or near enough to it to evaporate. When this salty water evaporates, which is very quickly in the arid West, the salt remains and rapidly accumulates. After this happens, no plants can grow. Due to capillary rise of water in soils, excessive salinity can and often does occur in the root zone even when there is not waterlogging of the root zone.

These are the things that must be controlled, and only by proper management of irrigation and adequate drainage can they be controlled. The salt must be kept within acceptable limits in the root zone by irrigation with the application of more water than the plant can consume. At the same time, groundwater must be kept below the depth that causes waterlogging of the root zone. There is complete failure of agriculture when the salts become excessive or the groundwater becomes too high.

Note that there is a delicate balance here in that water has to be applied in excess of the crop needs but that excess application can cause groundwater levels to rise. The key to this delicate situation is often management. Water conservation is receiving a lot of attention, but without proper management, the water conservation program alone could create as much of a problem as waterlogging. The relationship between water conservation and management is all important for the sustainability of a productive soil environment. Just as there are many types of water conservation programs, there are also many types of related side affects. Let’s consider a few examples.

Water conservation through use of buried pipe laterals, canal linings, and other improvements to reduce seepage loss are effective in retaining more water in the distribution system for the user. Two of the side effects of reduced seepage loss are the removal of the local aquifer recharge and the loss of artificially created wetlands. The wetlands may or may not have any value, but they need to be considered in the overall scheme of the conservation program. Buried pipe laterals can improve the management operations of the delivery system as well as conserving water by reduced seepage loss, but the loss of the strip of lateral right-of-way is often a loss of upland habitat. Improvements in farming efficiency, as well as reduced operation and maintenance (O&M) costs, often exceed the benefits of retaining this piece of habitat.

On-farm water conservation issues can be centered on management to strive for more efficient use of irrigation water. The goal of the on-farm conservation program is to apply water to crops at the time the crop needs it and only in the amount needed to sustain maximum growth. The side effects of this type of conservation are reduced surface runoff and reduced deep percolation to the water table. Reduced surface runoff is desirable both from a conservation standpoint and also from a reduction of the nonpoint source pollution potential. A reduction in deep percolation is not always as desirable. The importance of deep percolation cannot be overlooked when considering water conservation measures. The salt balance in the soil can be readily upset by salts that come in with the irrigation water and remain in the soil profile. Without the flushing that occurs from deep percolation, the soil becomes less and less suitable for crop production.

To avoid this scenario, the planners of water conservation programs need to consider the amount of salts in the irrigation water, the required limits of salts in the root zone for the types of crops grown, the contribution of seasonal rainfall (if any), and the leaching requirement of the irrigation water for maintenance of the salt balance. Water conservation goals can then be set to ensure that the least amount of water will be used without creating harmful side effects.

Generally, most western crops have deep roots capable of reaching water below the more arid surface layer. An exception would be in areas with long growing seasons where double cropping of shallow-rooted vegetable crops is possible. Deep-rooted crops need a well-drained zone about 4 feet or more deep. This requires that the noncapillary, or gravity, water will move out of the root zone in about 24 hours after irrigation so the roots can get air. If this zone is saturated longer, the plants begin to suffer; if saturated too long, they die. In planning a drain system, consideration must be given to the height to which groundwater can be allowed to rise and saturate the soil and the required rate of removal of the excess groundwater. This rate will depend on the hydraulic conductivity, or permeability, of the soil and on the storage capacity available below the roots to receive this water and store it as it gradually lowers and moves into drains. There must be enough drainage to allow the storage space to be available again for the next deep percolation event. Storage capacity of a soil is measured by its specific yield characteristic, which is the amount of noncapillary pore space in the soil that will hold water and allow it to run out by gravity. If it has no place to go, the soil is saturated or waterlogged. Specific yield and permeability are two important soil characteristics to be measured during an investigation for designing and building drains. These factors, plus depth to barrier and the amount of deep percolation to be handled, largely determine drain spacing and depth which, in turn, determine the costs of drainage.

Although some people of the irrigated West have been talking drainage for over 50 years, most of the real understanding of the pertinent phenomena has come in the last 40 years or so; the analytical capability has come mostly in the last 25 years. Earlier work focused on a practical approach of cut and try, which always resulted in some waste and some unsuccessful work. The principal factors that generated recent progress were signs of mounting problems and a real desire of the farmers and irrigation districts to face and resolve them in view of the comparative agricultural and national prosperity.

Those really interested in drainage and those responsible for getting it done economically had to start practically from scratch in building a sound technical approach to sure-fire handling of drainage problems. It was soon learned that the provision of adequate drainage at least cost, or the accurate prediction of the drainage and money that would be required to protect lands that were proposed to be irrigated, demands a study of the problem and the collection of data. In other words, an investigation, because the irrigated valleys of the West usually present a complex relationship of soils, water, crops, and irrigation practices that must be evaluated to varying degrees in the economical solution of drainage problems.

Some drainage problems and, hence, some drainage investigations are much less complex than others. Although investigations should be kept to the minimum commensurate with satisfactory results, that part of the drainage dollar spent on investigations is usually well spent and very seldom, if ever, can economies in drainage construction be achieved through skimping on investigations.

A key factor in drainage or in drainage investigations is the water table. Irrigators, irrigation district management, agriculturists, and engineers orient much of their work around the water table. Successful irrigated agriculture in an arid environment requires good control of the water table. The basic questions to be answered in drainage investigations usually boil down to:

- Where is the present water table?
- Is the water table rising or is it static?
- Where can the water table be expected to level off with continued irrigation?
- Is the water table too high or will it be too high when it reaches equilibrium?
- What manmade works are required to control the water table at safe levels?
- What will be the cost?

One of the first steps in a drainage investigation is to determine the source of the groundwater causing the problem. The source must be known so that the proper protective measures can be undertaken. As a first step, local irrigation practices should be observed and the amount and distribution of their irrigation should be discussed with farmers. Attempts should be made to determine whether the problem is or may be expected to be general for the whole area or whether it is applicable only to specific portions of the area. Perhaps the area has always had poor natural drainage and the drainage problem is merely the result of encroachment of irrigation upon natural conditions. The problem may have developed from construction of a dam or a leaky canal or it may have developed from changes in irrigation practices. Sometimes it may be the result of cycles of high rainfall, the expansion of irrigated areas, or of periods when excessive irrigation water has been applied.

At least some investigational data are normally needed to go further into the problem and pinpoint the source of the groundwater. Test borings and observation wells will indicate groundwater levels, directions of movement, fluctuations, and possible causes. Some in-place permeability tests are usually essential. In addition to the permeability of the principal strata, data are needed on the type of soil and thickness, position, and continuity of such strata. It has been learned, sometimes the hard way, that no matter how favorable the soil and subsoil characteristics of an area appear to be, at least some knowledge of deeper substrata is also required.

There are only a few sources from which groundwater can come, and it is usually not too difficult to pinpoint the source causing the trouble. Even in the Western States, rain can sometimes be the cause of the high water table, so precipitation records should be compared with groundwater levels. To determine whether excess irrigation is the source of the drainage problem requires a study of the effect of individual irrigations on the water table, the fluctuations of the water table throughout the irrigation season and during times of no irrigation, and changes in water table elevations over a period of years, both before and after the beginning of irrigation.

In many drainage problem areas, seepage is a major source of the groundwater. Most seepage comes from canals, laterals, reservoirs, or the irrigation of higher lying lands. Here again, comparisons are made of groundwater fluctuations with water levels in, or the presence of water in, canals or reservoirs or with irrigation at higher levels. Sometimes cattails, willows, or other water-loving plants indicate seepage and a possible source of recharge. Other methods of detecting seepage involve the use of piezometers. Quantifying the seepage loss can be done by ponding tests in the canal.

Artesian pressure is sometimes a source of high water tables. In this case, piezometers are needed to define the problem and solution. Artesian pressures are usually found where a slowly permeable layer overlies a saturated permeable layer whose source of groundwater intake is at a higher elevation. Water may be forced upward into the root zone, through the slowly permeable layer or through fractures, displacements, or permeable lenses in this layer. Sometimes old artesian wells leak below the ground surface or are allowed to run freely without proper facilities to dispose of the surface flow. Drainage problems under artesian conditions are usually difficult to pinpoint and more costly to solve.

Once the source of the high groundwater is determined, a start has been made on the solution to the drainage problem, and it will then be known what additional information will have to be obtained. This would usually include more data on groundwater levels and fluctuations, salt concentrations in both water and soil, past and probable future irrigation and cropping practices to permit evaluation of irrigation schedules and deep percolation, quantitative losses from irrigation channels, and permeabilities of soils, subsoils, and the stratification thereof. More or less standard techniques have been developed for obtaining this information, but skill and good judgment are required to get reliable answers.

After the investigations are completed, what can be done about removing the excess water and the salt? The groundwater table can be lowered and the salt can be moved by leaching it. In leaching, still more water is put on to dissolve the salt in the soil and move it to safe depths. But more water cannot be put on until a place is provided to put it because the groundwater would only be raised still more and then all the problems would be intensified. Drainage is the solution.

There are several kinds of drains. Open drains are simply open ditches excavated to the right depths for the local conditions. Closed drains are constructed by burying pipe in the water-bearing strata. Closed drains have the great advantages of eliminating weed and silt problems and of permitting cultivation over the drain. There are also other kinds of drains that are not so well known. Pumped wells are one. The Salt River and Wellton-Mohawk Valleys in Arizona, as examples, are drained by pumped wells. These wells remove groundwater, which is the objective of drainage. Sometimes the water can be reused by mixing it with canal water and sometimes it cannot because of the water quality.

Another method of drainage that many people are not familiar with is by inverted or recharge wells. These are upside-down wells. Instead of taking water out of the ground, they are used to put water into the ground in places where it will do no damage. Inverted wells serve as drainage outlets. First, there usually is some kind of a conventional drainage system that gathers the water and takes it out of the root zone. Then, where no natural or cheaper outlet is available, wells are drilled into unconfined aquifers that can take the water conveyed to them from the drains. There are examples of inverted well drainage in Idaho and in Texas. In the Snake River country of Idaho, some of the underlying basalts are fractured, and the water that gets into this material through inverted wells eventually finds its way to the river through subsurface channels. However, many of these wells have been ordered closed due to environmental considerations. Environmental restrictions must be followed when considering the use of inverted wells.

In recent years, disposal of drain system flows has become subject to water quality standards. The quality and estimated quantity, including specific constituents of drain flows, must be determined before a disposal method can be selected. For most locations, mixing with existing surface flows will be adequate. Local and State regulations should be checked before a disposal method is selected. Some States require onsite disposal when base quantities of certain elements or agricultural chemicals are exceeded. Remember that maintaining salt balance in the soil profile is a primary goal of drainage. Any plan that does not meet the salt balance goal is not a long-term solution to the drainage problem.

Up to about 1972, pipes for closed drains were made with clay or concrete, but now most subsurface drains are constructed with corrugated plastic drain pipe. Specifications have been developed for the plastic drain pipe, which include requirements that ensure a long life when installed properly. Irrigation districts should try to develop the best drain designs and use the best material for the purpose so their farmers get the most for their money over the long haul. To do this, the drains sometimes require more initial investment in materials, in methods of placement, and in quality of design than would shorter-lived structures.

Most drainage specialists of this country are convinced that closed subsurface drains are much better than open ones, except where capacity requirements are so great that the size of closed drains would be prohibitive in cost or where considerable surface waste or storm runoff must be handled. Pump well drainage and inverted well drainage are used only in special instances in which aquifer conditions are ideal and the costs are less than for open or closed drains. Feasible pump well drainage requires low-cost electric power and chemical characteristics of the soil and water that permit long life of the well components.

In most localities, costs of closed drains are less than for open drains of the same depth if all factors are considered. Maintenance costs of properly designed closed drains are insignificant compared with those for open drains, and the productivity value of the land taken out of cultivation by the open drain is appreciable, whereas all the land over closed drains can be cultivated.

The cost of drainage is an important economic factor, deserving of serious thought. Although there are many miles of drains already built on irrigation projects, this is only a fair start on the total needed for optimum productivity of irrigated western lands. Economic fluctuations have had some affect on rate of drain installation, more so in the humid areas, however, than in the irrigated arid lands. Drainage in the West, because of the salinity and seepage factors, is so often vital to good productivity, even for pasture. Since farmers, as well as public and private financial assistance agencies, now know much more about the benefits of drainage than they did 25 years ago, progress will continue year after year, even through economic depressions.

While there are some exceptions, today's costs for providing adequate drainage for irrigated lands range from about $100 to over $1,000 per acre. This is a high price for most farmers to accept and finance, even though they can see the ultimate benefits. Most of these costs are in the material and the installation. The improvements in the use of plastic pipe have been much greater than the advances in equipment well suited to construction of good closed drains. Few contractors are equipped to install efficiently, for example, a first-class, 10-foot-deep closed drain. Most drainage requirements are progressive—an area here this year, one there next year—and therefore contracts are usually small compared with those for construction of other phases of irrigation projects. The work being small, scattered, and usually spread over several decades, is not sufficiently attractive to substantial contractors who would have to buy drain trenching equipment for the job. This results in little competition, limited generally to small, local contractors, and high costs. Many contractors are equipped only with draglines, backhoes, and similar equipment, which usually cannot perform efficiently on drainage work, but a few have trenchers capable of excavating up to 12 feet or more. Trenchers capable of placing drains at 20 feet have been developed.

Drainage contractors in irrigated areas of the West have developed specialized pipe laying trenching machines that do a good job at minimum cost. The most versatile of these rigs will dig trenches up to 12 feet deep; place or permit easy and safe placing of the pipe in the trench; and place gravel envelope under, around, and over the pipe; all without caving. Some also backfill the trenches over the pipe. Where such machines are locally available, contract costs are often much less than where the contractors have only conventional excavating equipment. It would undoubtedly be wise for some irrigation districts to invest in such highly efficient, specialized drain construction equipment.

Through the years, various formulas have been used for determining drainage requirements such as depth, spacings, and discharge capacities. These formulas have been based mostly on empirical concepts and opinions or experiences of individuals rather than on more exact engineering methods. With luck, the drainage job or estimate came out about right. Frequently, however, the guesses were too far off, or the empirical relations were not applicable to the particular case. As a result, many irrigation districts suffered in various ways. In recent years, substantial technical breakthroughs have been made in this regard.

Ways have been developed to use measurable soil and irrigation factors to compute more accurate answers than ever before possible with empirical data and variable judgment. Measurable field data can now be taken on soils and substrata from any place, any amount of recharge from either rain or irrigation can be assumed, and the spacing of drains that will be required to control the groundwater table under any irrigation, operating, or cropping conditions can be accurately estimated. Not only can the elevation of the water table be considered, but the time during which it encroaches upon the root zone, the time required for it to decline to a predetermined level, and any seasonal variations can be specified.

These new methods of predicting and determining subsurface drainage requirements have been proven by comparing computed drain spacing and water table behavior with measured values for areas where drains were already installed. Data on groundwater position and fluctuations, drain discharge measurements, and permeabilities have been used to compute spacings that would be required to give the same amount of water table drawdown as had been actually measured in the field. In one such study, 67 comparisons were made from such widely separated irrigated areas as Australia, Canada, and the Southwestern United States. Computed water table elevations at specific time periods were within 5 percent of the measured height in 54 percent of the cases, within 10 percent in 79 percent of the cases, and within 15 percent in 88 percent of the cases. Groundwater prognoses, historically, have never before been nearly this accurate, so these results are highly gratifying and confirm the usefulness of the new methods. These results also amply demonstrate the value of in-place permeability tests. Such tests, when field-tested procedures have been followed, undoubtedly provide values of permeability that are realistically close to the actual.

Drain spacing and depth are interdependent and for given conditions there is an economically optimum combination. For some lands, 7-foot-deep drains 200 feet apart might be least costly, while in another area, 12-foot-deep drains 800 feet apart might be less expensive. Spacings may vary from 50 to 1,500 feet. Nine feet is a practical depth for most closed drains, but the size of pipe, depth, and spacing must be selected on the basis of the physical characteristics of the substrata and the amount of deep percolation to be handled, which depends on the local land use and irrigation practices. Once the proper determinations of location, spacing, and depth have been made, the construction designs for closed drains are simple compared to many other irrigation structures. Even so, several basic elements of design are necessary for an efficient drainage system.

One highly desirable element is a gravel envelope around the drain pipe. The total number of drains needed for a required job can sometimes be reduced as much as one-half simply by using the right gravel envelope. Usually, at least 4 inches of gravel should be placed completely around the pipe. This will help stabilize the pipe and prevent movement into the pipe of the soil being drained, and at the same time act as a conductor for movement of water from the soil into the openings in the pipe. For plastic drain pipe, the gravel also serves as a support for the flexible pipe. An all-important rule is that permeability of the envelope must be high compared to permeability of the soil, sometimes called the base material. Some pit-run gravel will meet the requirements. The gradation of the envelope should be well graded with nothing larger than 1½ inches and less than 5 percent passing the No. 200 screen.

Other elements of good closed drains are manholes, junction boxes, or silt traps. These are valuable because they provide better inspection of a newly constructed line, easier and cheaper cleaning and repair, and a means of finding blockages and measuring discharges of individual segments of the line. The last operation in constructing an effective closed drain is a careful job of backfilling to ensure that the gravel stays in place and the pipe joints are not moved or broken, and to ensure that the surface is left as close to original conditions as possible.

Finally, after the drains have been built and water is flowing from the outlet, there are a few things that should become part of the regular O&M program. If the drain system becomes clogged or flow from the outlet becomes restricted, then the same sequence of events that occurred prior to drain construction will begin to happen again. The symptoms of a shallow water table, the yellowing of crops, the appearance of salts, prolonged wet soils, or the re-appearance of cattails are a sign that the drains are not functioning properly. These should be a warning sign to get out into the field and check the drains. Regular inspections as a part of the O&M program can help to prevent crop damage if the maintenance is kept current.

What are some of the things to look at during the O&M inspection? To begin with, the outlet should allow water to flow away without backing up against the pipe. From there, the manholes can be opened and visually checked to see if the water level is below the pipes entering and leaving the manhole. Restrictions or blockage downstream from the manhole will cause water to backup and create a "head" in the manhole. Blockages upstream from a manhole may be indicated by slowly moving water or a quantity of flow that is less than normal, but this is usually hard to detect without using some type of flow meter. Keep in mind that the flows in a drainage system are a reflection of the groundwater conditions in the area. If the seasonal rainfall is above normal, then the area groundwater levels may be high and consequently greater flow may be observed in the drains. Also, during the irrigation season, greater flows in the drains may be observed due to on-farm irrigation and canal seepage contributions. Over the winter months, or non-irrigation season, water levels in the manholes should all be normal, and some decrease in the flow rate may be observed. The flow rate should reflect the seasonal variations of the groundwater levels.

All in all, profitable farming operations and financially healthy irrigation districts are ensured if:

- Drainage problems are approached with the knowledge available today
- Designs are properly developed for the conditions
- Good construction is insisted upon
- The irrigation district consistently conducts a first-class maintenance and water management program
- Farmers wisely perform their job of good water and land use

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