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Table 0.0 Document status

No	Category	Value
1	Client id	any
2	Budget No	01
3	Contract type	DPS
4	Project description	standard SWRO plant of 96000 m3/day
5	Country	Other
6	Date	2015-08-22
7	Contact person	

Availability analysis scope and procedure

The plant availability analysis (PAA) is based on a number of assumptions which are well accepted in the water industry. They relate to idealization of the real failure phenomenon and the assumptions regarding client O&M capabilities.

1. Components are repairable and the failure is always localized and do not propagate outward
2. The failure rate is constant
3. Preventive maintenance is executed according to the equipment manufacturer guidelines
4. The equipment is operated within the range allowed by the manufacturer
5. Spare parts stock is well maintained
6. The component on-line fault detection covers all of the plant�s systems and critical components

The bricks of any availability analysis are the component mean time between failures (MTBF) and mean time to repair (MTTR) values.
MTBF can be described as the time that passes before a component, assembly, or system fails, under the condition of a constant failure rate. Another way of stating MTBF is the expected value of time between two consecutive failures, for repairable systems.

MTTR is defined as the total amount of time spent performing all corrective or preventative maintenance repairs divided by the total number of those repairs. It is the expected span of time between a failure (or shut down) to the completion of the repair or maintenance.
Maintainability is defined as the probability of performing a successful repair action within a given time. In other words, maintainability measures the ease and speed with which a system can be restored to operational status after a failure occurs.
The availability of a component, system or the entire plant is expressed through the MTTR to MTBF ratio (see Equation 1 below).
As mentioned above, MTTR is the sum of unplanned and planned repairs. The frequency and duration of the first is probabilistic in nature, whereas those of the latter are recorded in O&M books. This is why it is natural to represent unavailability as a sum of two parts - the planned and unplanned one (Equation 3).
The focus of this document is on unplanned availability, so for the sake of simplicity, the availability word is used without the unplanned prefix.
Availability of the desalination plant is a product of the production rate availability and the product quality availability; both are pronounced functions of the plant load. As a rule, plant unavailability goes down at decreased loads with the product quality being less reliable.
Plant availability is calculated by modeling the system as an interconnection of operating modules or blocks in series and parallel, called reliability block diagram (RBD). RBD is an exact replica of the process flow diagram (PFD) used by the process engineer or the control flow graph (CFG) as starting point for the control engineer.
The following rules are used to decide if modules should be placed in series or parallel.

1. If module failure leads to the combination becoming inoperable, the two modules are considered to be operating in series. The combined availability of two modules in series is always lower than the availability of either of them.
2. If module failure leads to the other modules taking over the operations of the failed module, the two modules are considered to be operating in parallel. The combined availability of two modules in parallel is always much higher than the availability of either of them.

The availability of the N modules connected in train is defined by Equation 6, where a is the availability of a stand-alone module.
The availability of the identical modules connected in parallel depends upon the quantity of operating modules (N) and the one of the standby modules (S).
If the desalination plant is resistant to the faults and failures of a certain module, it should be excluded from the consideration. For example, the traveling band screen of the intake stations may be operated for a relatively long duration of time with the backwashing system tripped. Another example is the chemical dosing systems; their failure levels which are as low as 50% output for 1-4 hours is tolerated well by the desalination process. These systems are considered as fail well.
The same principles apply to the module availability calculation starting from the analysis of the item connections inside the module and collecting data on the item�s MTBF and MTTR values.
All instrumentation of the control loops and the safety interlocks are included in the module availability calculation by default.
Prone to failure components include all rotating equipment with associated motors, gear boxes and VSDs, valves and fittings under pressure, RO membranes and connections, and main electric equipment. Power and instrumentation cables and cable terminals are not taken into account.
All the mentioned components shall be checked against P&IDs, instrument index and interlock list to ascertain that all failures in question are covered by the designed failure detection system.

$$Availability = \frac{MTBF}{MTBF + MTTR} \qquad (1)$$

$$Unavailability = 1 - availability \qquad (2)$$

$$Plant\ availability = Availability_{planned} * Availability_{unplanned}$$

$$Plant\ availability = Availability_{production} * Availability_{quality}$$

$$Availability_{module} = a_1 * a_2 * a_3 * \ldots .* a_n \qquad (5)$$

$$Availability = 1 - F * (1 - a)^{S+1}, \qquad where\ F = \frac{(N + S)!}{(N - 1)! * (S + 1)!}$$

Figure 1 equations

Table 1.0 Mtbf and mttr values database

No	Equipment class	MTBF,h	MTTR,h	Items Qty
1	pro/CO2 dosing	100000	4	1
2	hex/plate	100000	4	1
3	valve/globe/throttling	40000	4	
4	valve/manual/root valve	160000	4	16
5	valve/manual/drainage	100000	4	47
6	valve/manual/isolation	160000	4	111
7	valve/manual/isolation/#300	80000	4	
8	valve/manual/isolation/#600	80000	4	3

No	Equipment class	MTBF,h	MTTR,h	Items Qty
9	valve/with gearbox/isolation	160000	4	6
10	valve/with gearbox/drainage	100000	4	1
11	valve/electromechanic/control/#150	40000	4	3
12	valve/electromechanic/control/#300	20000	4	
13	valve/electromechanic/control/#600	20000	4	
14	valve/electromechanic/throttling/#150	40000	4	1
15	valve/electromechanic/throttling/#300	20000	4	
16	valve/electromechanic/throttling/#600	20000	4	1
17	valve/electromechanic/isolation/#150	80000	4	45
18	valve/electromechanic/isolation/PN10	80000	4	2
19	valve/electromechanic/isolation/#300	40000	4	
20	valve/electromechanic/isolation/#600	40000	4	3
21	valve/electromechanic/drainage/#150	80000	4	4
22	valve/electromechanic/drainage/#300	40000	4	
23	valve/electromechanic/drainage/#600	40000	4	
24	valve/ball/throttling/#150	80000	4	
25	valve/ball/throttling/#300	40000	4	
26	valve/ball/throttling/#600	40000	4	
27	valve/nonreturn/protection	45000	4	17
28	valve/nonreturn/high cycle operation	20000	4	
29	valve/pressure relief	32000	4	15
30	valve/solenoid	40000	2	52
31	valve/rupture disc	40000	2	2
32	valve/diaphragm	40000	2	7
33	valve/pressure-reducing	40000	2	14
34	pump/vertical turbine	40000	8	3
35	pump/overhung horizontal	50000	8	7
36	pump/between bearings	60000	8	6
37	pump/between bearings/#600	50000	8	1
38	pump/recessed impeller	20000	4	
39	pump/axial flow	80000	8	
40	mep	40000	4	14
41	mep/progressive cavity	30000	4	
42	mep/helical gear	30000	4	
43	mep/rotary vane	30000	4	

No	Equipment class	MTBF,h	MTTR,h	Items Qty
44	mep/positive displacement	30000	4	
45	motor/direct on line/auxiliary	120000	8	
46	motor/direct on line/continuous	80000	8	7
47	motor/direct on line/batch	40000	8	13
48	motor/variable speed drive/continuous	160000	8	8
49	motor/variable speed drive/batch	100000	8	3
50	vsd	100000	8	11
51	sst	100000	24	3
52	meter/vibration	40000	2	31
53	meter/temperature	50000	2	45
54	meter/conductivity	18000	2	7
55	meter/pH	18000	2	7
56	meter/turbidity	18000	2	3
57	meter/redox	18000	2	2
58	meter/free Cl	18000	2	4
59	meter/silt density index	18000	2	1
60	meter/flow	27000	2	24
61	meter/flow/switch	27000	2	3
62	meter/level	30000	2	45
63	meter/level/switch	30000	2	26
64	meter/pressure	77000	2	68
65	meter/pressure/switch	33000	2	4
66	air	19000	24	17
67	vacs	40000	24	
68	mixer/high intensity	40000	24	8
69	mixer/coagulate	50000	24	
70	mixer/flocculate	50000	24	
71	mixer/neutralize	50000	24	
72	mixer/scrape	64000	24	
73	mixer	50000	24	7
74	filter/centrifuge	18000	24	
75	filter/rotary screen filter	20000	4	1
76	filter/temporary strainer	10000	2	5
77	filter	50000	4	29
78	fitt	100000	2	39

No	Equipment class	MTBF,h	MTTR,h	Items Qty
79	piping	100000	6	248
80	vite/reduction gear	100000	8	
81	vite/conveyor	10000	24	
82	fitt/mixer	120000	4	
83	vessel	40000	4	34
84	vessel/concrete/polyethylene	20000	24	2
85	ert	80000	24	22
86	derd/DWEER work exchanger	45000	24	
87	derd/ERI pressure exchanger	120000	4	1
88	filter/cartridge filter	120000	4	2
89	filter/RO membrane	120000	4	1
90	igroup/transformer	390000	24	
91	igroup/switchgear	100000	24	
92	cabterm/PLC	33000	4	

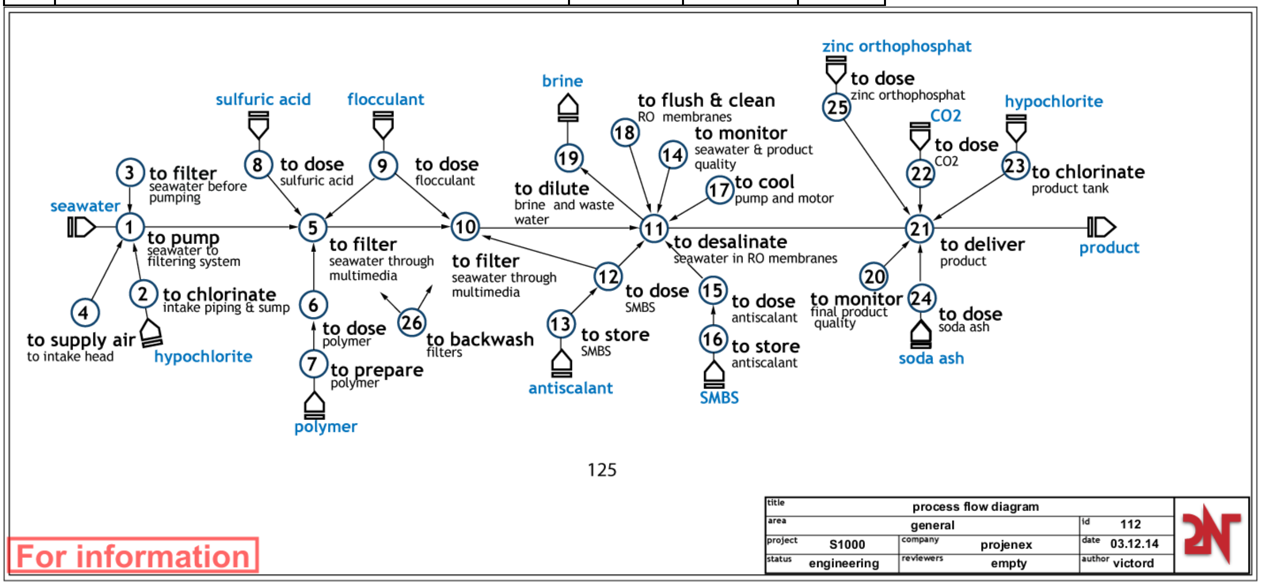

Figure 2 P&ID 112: process flow diagram

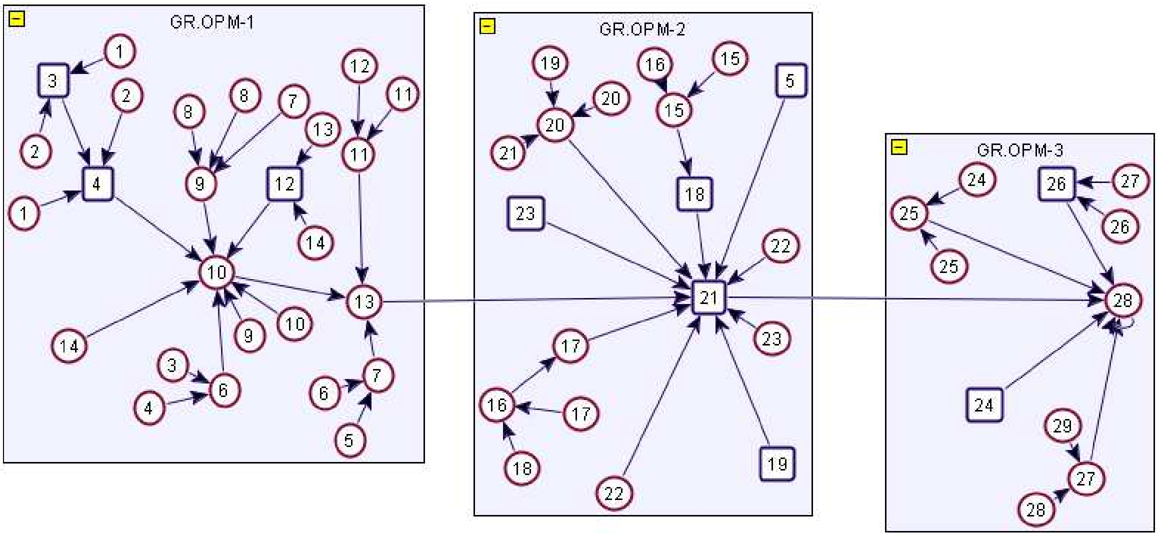

Figure 3 reliability block diagram for S1000 project

Table 2.0 Plant reliability data for 100% load

No	PFD node	Description	Operated capacity	Standby capacity	SF	Fault	Affects
1	SW-MC-1	to pump seawater to filtering system	100	10	1	0.00365	Q
2	SW-MC-2	to filter seawater through multi-media stage 1	100	10	1	0.00364	Q
3	SW-MC-3	to filter seawater through multi-media stage 2	100	10	1	0.00407	Q
4	SW-MC-4	to filter seawater before pumping	100	50	1	0.00022	Q
5	HCL-AB-5	to chlorinate intake piping and sump	100	0	0.05	0.00009	Q
6	AIR-AB-6	to supply air to intake head	100	0	0.05	0.00008	Q
7	PMR-AB-7	to prepare polymer	0	0	1	0.00095	Q
8	PMR-AC-8	to dose polymer	100	0	1	0.00071	Q

No	PFD node	Description	Operated capacity	Standby capacity	SF	Fault	Affects
9	FLCNT-AC-9	to dose flocculant to filter 1	100	0	1	0.00107	Q
10	FLCNT-AC-10	to dose flocculant to filter 2	100	0	1	0.00062	Q
11	H2SO4H-AC-11	to dose sulphuric acid to stage 1	100	10	1	0.00038	Q
12	SW-AC-12	to dilute brine	100	0	0.8	0.00021	Q
13	PW-MC-13	to desalinate seawater in RO membranes	0	5	1	0.03697	Q
14	ASL-AC-14	to store antiscalant	100	0	0.05	0.00006	Q
15	ASL-AC-15	to dose antiscalant	100	20	1	0.0074	Q
16	SMBS-AB-16	to store SMBS	100	0	0.05	0.00006	Q
17	SMBS-AC-17	to dose SMBS after filter 2	100	20	1	0.00185	Q
18	SMBS-AC-18	to dose SMBS to SWRO	100	20	1	0.0074	Q
19	PW-AB-19	to flush RO membranes	100	20	0.05	0.00003	Q
20	CIP-AB-20	to clean RO membranes	100	20	0.05	0.0007	Q
21	SRW-AC-21	to cool equipment bearings and motor	100	50	1	0.00126	Q
22	PW-MC-22	to deliver product	0	0	1	0.00136	Q
23	ZOP-AC-23	to dose zinc orthophosphat	100	20	1	0.00093	Q
24	SRW-AC-24	to dose lime water	100	10	1	0.0021	Q
25	CO2-AC-25	to dose CO2	100	0	1	0.00043	Q
26	HCL-AB-26	to chlorinate product tank	100	10	0.05	0.00003	Q

No	PFD node	Description	Operated capacity	Standby capacity	SF	Fault	Affects
27	BR-AB-27	to backup filters backwashing	100	0	0.8	0.00158	Q
28	H2SO4H-AC-28	to dose sulphuric acid after stage 2	100	10	1	0.00091	Q
29	OIL-MC-1	lube oil system	100	50			
30	CO2-MB-1	CO2 dosing	0	0			
31		Plant availability				0.9235	

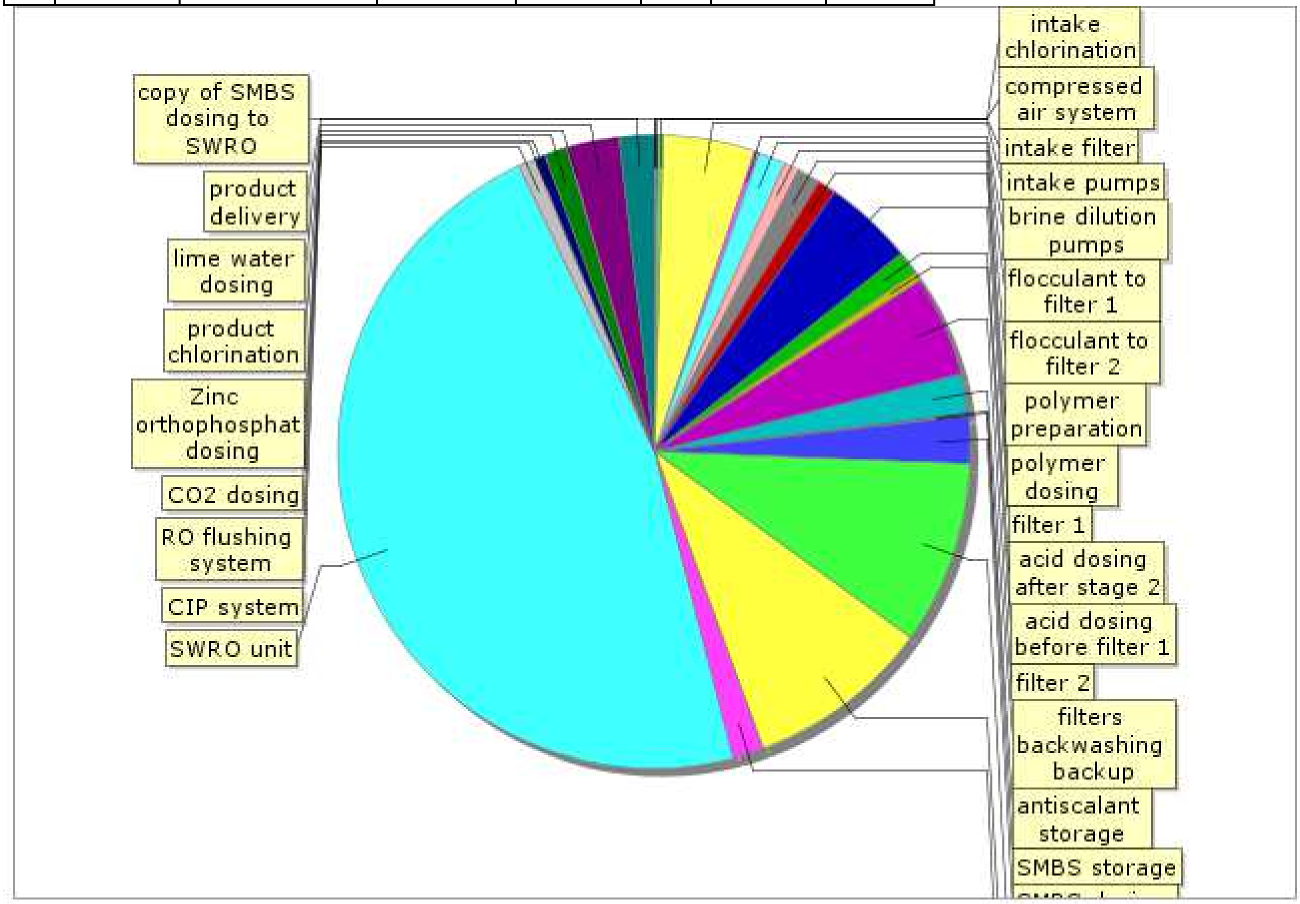

Figure 4 unavailability breakdown

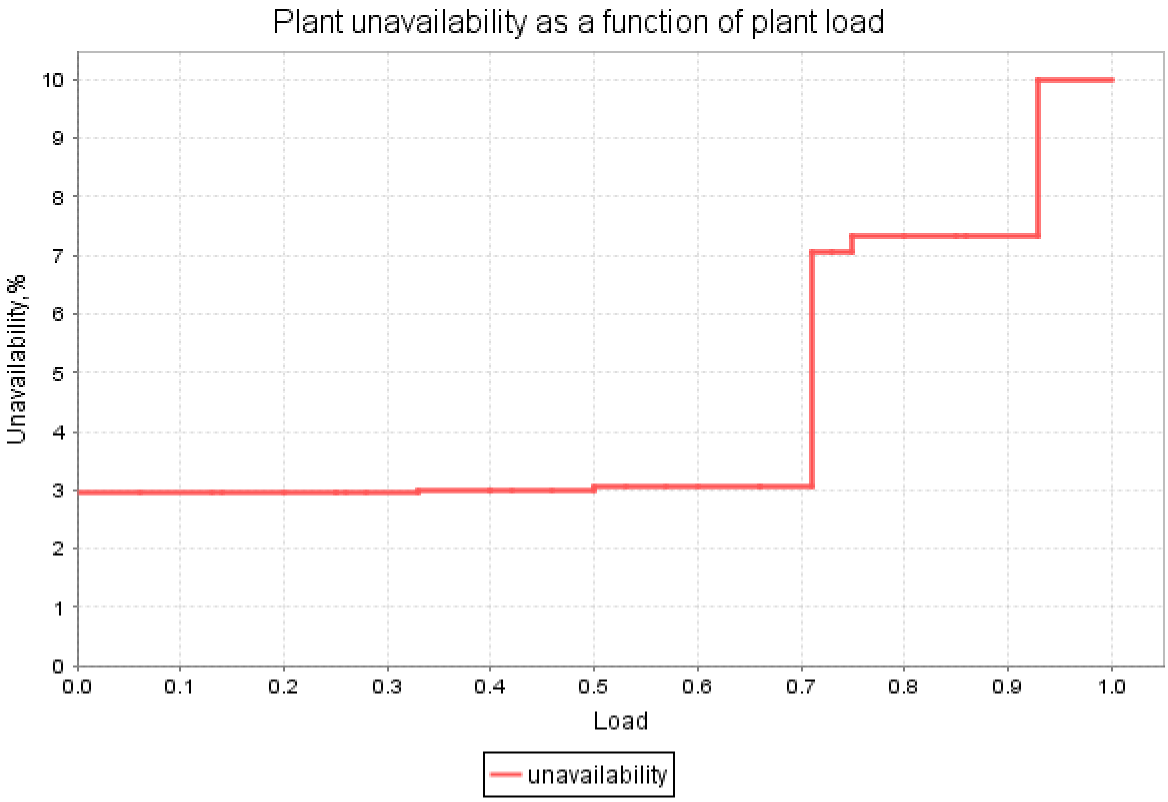

Figure 5 Plant unavailability as a function of plant load