WASTE STABILIZATION PONDS 6
Maturation ponds

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<td>This presentation is on maturation ponds, and these are the third type of pond that we commonly use.</td>
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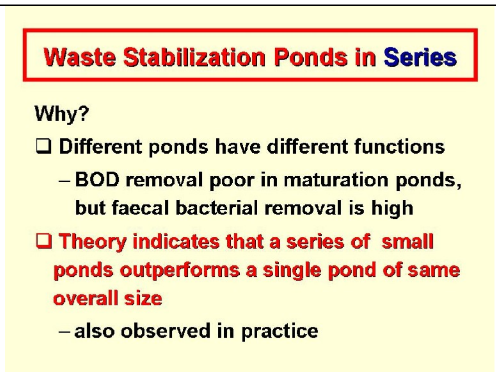

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<td>We use ponds in series because different pond types have different functions. BOD removal is good in anaerobic and facultative ponds, but poor in maturation ponds, which tend to be used for the removal of faecal bacteria and other excreted pathogens.

We know from theory, and we can observe this in practice as well, that a series of small ponds outperforms a single pond of the same overall size.</td>
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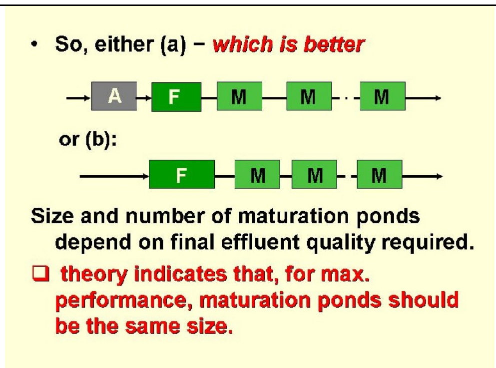

</td>
<td>So we have either series (a) shown on the slide or series (b), and there's a preference for series (a) as BOD removal in anaerobic ponds is so good.

The size and number of maturation ponds depends on the final effluent quality we need to produce; and for maximal performance the maturation ponds should all be the same size. This may not, of course, be possible, but at this, the process, stage of the design we assume that it is.</td>
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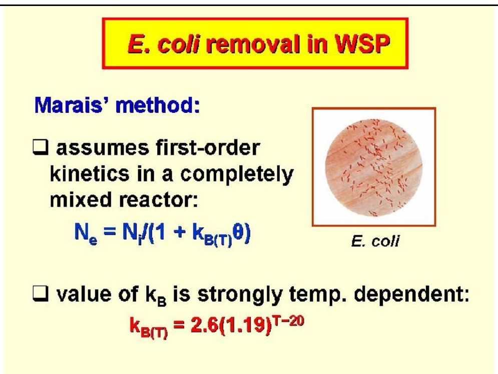
<td>4.</td>
<td>
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<td>We normally design maturation ponds for E. coli removal, although of course we might in any one case want to design them for something else − nitrogen removal, for instance.

We use the design method developed by the late Professor Marais: the first equation on the slide is the usual first-order equation for, in this case, E. coli removal in a completely mixed reactor; and the second equation is Marais' empirical equation for the variation of the first-order rate constant for E. coli removal, k_B, with temperature, and its value is strongly temperature-dependent, changing by 19% for every 1 degC change in temperature.</td>
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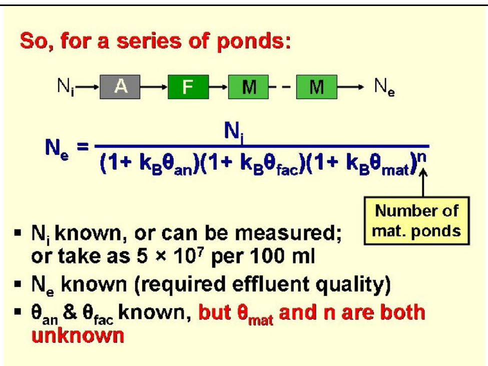
<td>
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<td>So for a series of ponds, and remembering that the effluent of one pond is the influent to the next, we can derive the equation for N_e shown on the slide. This basically says that N_e, the number of E. coli per 100 ml of the final effluent equals N_i, the number per 100 ml of the raw wastewater, divided by a term for the anaerobic pond, by one for the facultative pond, and by one for the maturation ponds raised to the power n, where n is the number of maturation ponds.

Now N_i is either known or taken as, for example 5×10^7 per 100 ml; N_e is known as it's the final effluent quality we need; and, at this stage in the design, we will have already designed the anaerobic and facultative ponds, so the retention times in these, θ_{an} and θ_{fac}, are also known.</td>
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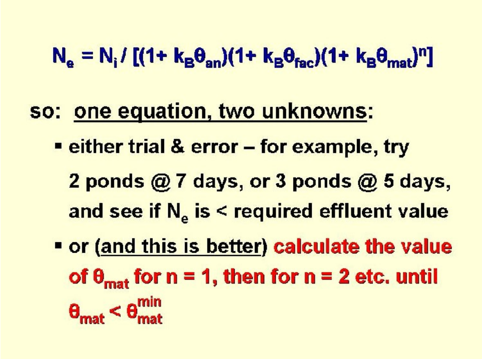
<td>6.</td>
<td>
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<td>So we have one equation with two unknowns. We can solve it either by trial and error, or (and this is better) by calculating the value of θ_{mat} for $n = 1$, then for $n = 2$, and so on until θ_{mat} is $< \theta_{mat}^{min}$, the minimum value of θ_{mat}.</td>
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7.	❑θ^{min}_{mat}: minimum value of θ_{mat}, in range 3–5 days. A min. value is assigned to prevent algal washout and reduce hydraulic short-circuiting. Marais recommends 3 days in warm climates (~5 days in temperate climates)	A minimum value of θ_{mat} is used in order to minimize hydraulic short-circuiting and the allow sufficient time for the algae to multiply. θ^{min}_{mat} has a value in the range 3−5 days: generally 3 days in hot climates and 5 days in temperate climates.
8.	❑θ^{min}_{mat}: minimum value of θ_{mat}, in range 3–5 days. A min. value is assigned to prevent algal washout and reduce hydraulic short-circuiting. Marais recommends 3 days in warm climates (~5 days in temperate climates) Solution to equation might be, for example: n = 1 θ_{mat} = 150 n = 2 θ_{mat} = 20 n = 3 θ_{mat} = 4.2 n = 4 θ_{mat} = 1.6 ....STOP!	So when we solve the equation for n = 1, n = 2, and so on, we might get the following results: For n = 1, θ_{mat} = 150 days; for n = 2, θ_{mat} = 20 days; for n = 3, θ_{mat} = 4.2 days; and for n = 4, θ_{mat} = 1.6 days. We would **stop** here as the last calculated value of θ_{mat} is $< \theta^{min}_{mat}$.
9.	(a) Ignore values of $\theta_{mat} > \theta_{fac}$ and $< \theta^{min}_{mat}$ (b) Choose the combination that requires least land (ie, the one for which the product of n and θ_{mat} is smallest) ➢ include in this comparison the combination of θ^{min}_{mat} and value of n for which θ_{mat} first goes below θ^{min}_{mat} (n = 4 in above example, for which θ_{mat} = 1.6 d)	So how do we interpret these results? Well, we would ignore values of $\theta_{mat} > \theta_{fac}$ (there's no theoretical basis for this, just 'engineering judgement'), and we obviously ignore values of $\theta_{mat} < \theta^{min}_{mat}$. We then choose the combination of n and θ_{mat} that requires the least land − that is to say, the combination for which the product $n\theta_{mat}$ is a minimum, and we would include in this comparison the combination of θ^{min}_{mat} and the value of n for which the value of θ_{mat} first goes below θ^{min}_{mat}.
10.	Therefore: 1. $\theta_{mat} \ngtr \theta_{fac}$ But also: 2. $\theta_{mat} \nless \theta^{min}_{mat}$ 3. BOD loading constraint: $\lambda_{s(M1)} \ngtr 0.75\lambda_{s(fac)}$ To calculate $\lambda_{s(M1)}$, first determine $L_{e(fac)}$ (= $L_{i(M1)}$) from first-order equation for unfiltered BOD removal with k_1 = 0.1 d^{-1} (or 0.3 d^{-1} if primary fac. pond)	Thus θ_{mat} can't be greater than θ_{fac}, nor less than θ^{min}_{mat}. But we should also consider a BOD loading constraint: clearly the BOD loading on the first maturation pond can't be greater than that on the preceding facultative pond, and it's better if it's quite a bit less than this; and I prefer to say that the loading on M1 can't be more than 75% of the fac. pond loading. To calculate $\lambda_{s(M1)}$ we first determine the effluent BOD from the fac. pond by using the first-order equation for *unfiltered* BOD removal with k_1 = 0.1 day^{-1} (or, if it's a primary fac. pond, with k_1 = 0.3 day^{-1}).

11.	In fact simplest to consider constraint # 3 first: $\theta_{M1} = 10L_iD/0.75\lambda_{s(fac)}$ [as $\lambda_s = 10L_iQ/A = 10L_iQD/AD = 10L_iD/\theta$] and follow the 4-step procedure →	In fact it's best to consider this loading constraint first and, using the equation on the slide, determine the minimum value of θ_{M1}, and then follow the four-step procedure which I'll now describe.
12.	**Maturation Pond Design** **Four-step procedure** Step 1: Calculate: $\theta_{M1}^{min} = 10L_iD/0.75\lambda_{s(fac)}$ $= L_{e(fac)}$ [unfiltered BOD]	The first step is the calculation of θ_{M1}^{min}, using the loading equation we've just derived.
13.	Step 2: Calculate retention time in second & subsequent maturation ponds: $\theta_m = \{[N_i/N_e(1+k_B\theta_a)(1+k_B\theta_f)(1+k_B\theta_{M1})]^{1/n}-1\}/k_B$ now the retention time in M2, M3 etc. Solve for n = 1, 2, 3 etc. and STOP when $\theta_m < \theta_m^{min}$ (3–5 days) – assume this happens when n = ñ	Step 2 is to calculate the retention time in the second and subsequent maturation ponds, using the equation we had before but now, as shown on the slide, with a term for M1. We solve this equation for $n = 1$, then for $n = 2$, and so on until θ_{mat} is $< \theta_{mat}^{min}$. Note that n is now the number of the second and subsequent ponds; it does not include M1.
14.	Step 3: Choose most appropriate combination* of θ_{mat} and n, <u>including</u> θ_{mat}^{min} and ñ * ie, the one for which their product is a MINIMUM, as this gives the least land area requirement	Step 3 is the selection of the most appropriate combination of θ_{mat} and n, including θ_{mat}^{min} and $\tilde{n}$, where $\tilde{n}$ is the value of n for which θ_{mat} first goes below θ_{mat}^{min}.

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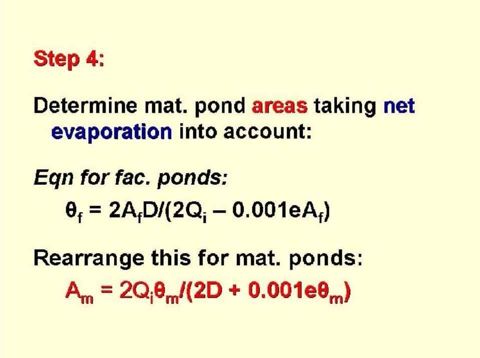
<td>
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<td>Step 4 is the calculation of the maturation pond areas, taking net evaporation into account. With facultative ponds we had the first equation shown on the slide, and for maturation ponds we need to rearrange this equation in terms of A, in fact A_m, as shown in the second equation on the slide.</td>
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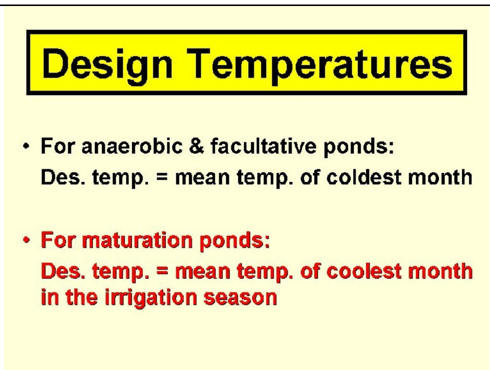
<td>
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<td>Now a word on design temperatures. For anaerobic and facultative ponds we have to use the mean temperature of the coldest month, as the ponds have to function properly at this lowest mean monthly temperature. With maturation ponds it’s less straightforward. If we were designing them for nitrogen removal, then we’d have to use the mean temperature of the coldest month; but if we’re designing them to produce an effluent suitable for agricultural reuse, then we’d use the mean temperature of the coldest month in the irrigation season.</td>
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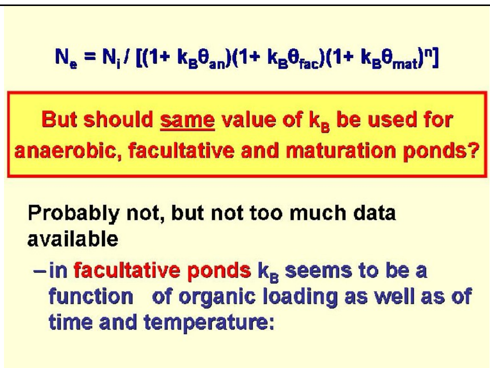
<td>
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<td>Going back to the design equation for E. coli removal in a series of ponds: it has to be asked whether we should use the same value of k_B in all three types of pond. The answer is probably not, but we don’t have too much data to say one way or the other, at least with any degree of confidence. But we do know that the equation is perfectly OK for a whole series of ponds, rather than for individual anaerobic, facultative or maturation ponds.

In fac. ponds the value of k_B seems to be a function of the BOD loading on the pond, as well as of time and temperature, …</td>
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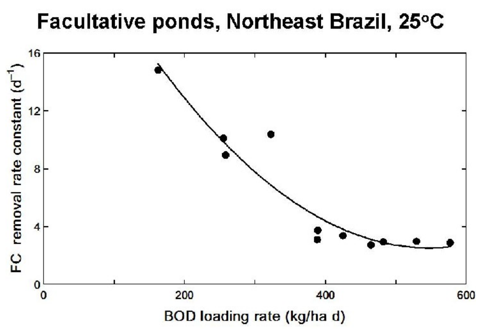
<td>
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<td>as shown in this slide for a primary facultative pond in northeast Brazil, which had a mean in-pond temperature of ~25°C. The value of k_B decreased fairly linearly with BOD loading in the range 200−400 kg per ha per day; thereafter it remained essentially constant.</td>
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19.

Performance of Five Ponds in Series

Northeast Brazil, 25 °C

June 1977 – May 1979

$\Sigma\theta = 29.1$ days

	Retention time (d)	BOD* (mg/l)	SS (mg/l)	FC (/100ml)
Raw w'w	–	240	305	4.6×10^7
A1	6.8	63	56	2.9×10^6
F1	5.5	45	74	3.2×10^5
M1	5.5	25	61	2.4×10^4
M2	5.5	19	43	450
M3	5.8	17	45	30

*Unfiltered

This slide shows the performance of a series of five ponds in northeast Brazil in the late 1970s. The anaerobic pond had a retention time of nearly a week, much too long really,[*] and the facultative and the three maturation ponds had retention times of ~5.5 days. Most of the BOD and SS were removed, as would be expected in the anaerobic pond, and the SS actually increased in the fac. pond − due to the growth of the algae; but the truly remarkable performance of the series is the removal of faecal coliform bacteria, more or less by an order of magnitude in each pond, down to 30 per 100 ml in the final effluent − a better bacteriological quality than the water most people in developing countries have to drink.

But the real point of results like these is that you can design a pond system to do more or less whatever you want. Pond systems are *flexible*.

[*] See the presentation on anaerobic ponds for further details.