WASTE STABILIZATION PONDS 4
Facultative ponds

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<td>1.</td>
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<td>This presentation is on facultative waste stabilization ponds.</td>
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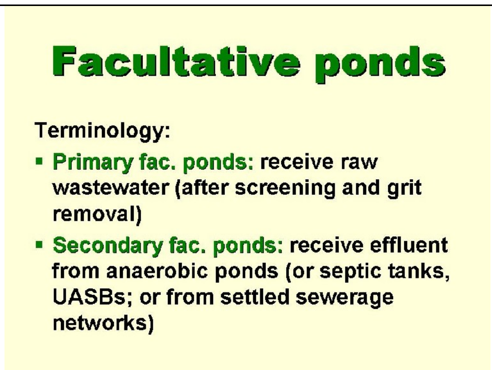
<td>2.</td>
<td>
</td>
<td>We use the term ‘primary’ facultative pond for fac. ponds that receive raw wastewater, and ‘secondary’ facultative pond for those receiving the effluent from an anaerobic pond or other settling device such as septic tanks, or the solids interceptor tanks used in settled sewerage.</td>
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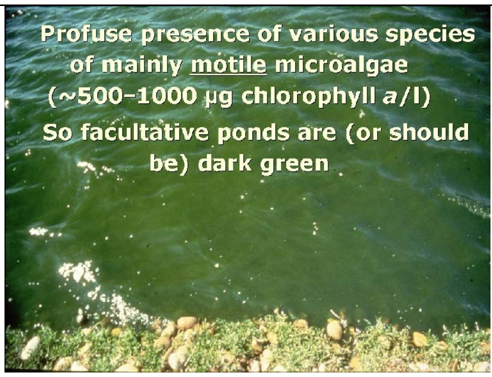
<td>3.</td>
<td>
</td>
<td>Facultative ponds should be dark green in colour as there is a profuse growth in them of mainly motile micro-algae. In a well performing facultative pond the algal concentration, expressed in terms of the main algal photosynthetic pigment, is around 500−2000 µg of chlorophyll a per litre.[*]

[*]The slide says ~500−1000 µg/l, which is more usual; but it can be as high as 2000 µg/l.</td>
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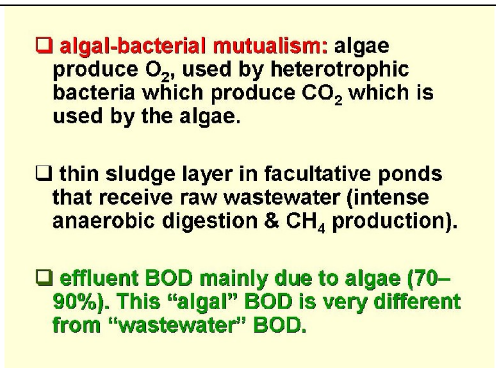
<td>4.</td>
<td>
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<td>In facultative ponds there is a mutualistic relationship between the algae and the heterotrophic bacteria: the algae produce oxygen which is used by the bacteria, and the bacteria produce carbon dioxide which is used by the algae.
There’s a sludge layer in primary fac. ponds and there’s intense anaerobic digestion in this layer with copious biogas production.
The BOD of a fac. pond effluent is mainly due to the algae in it, and this algal</td>
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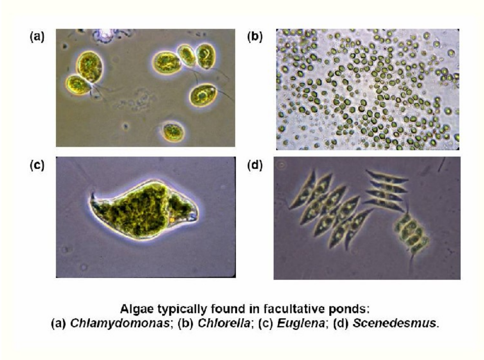
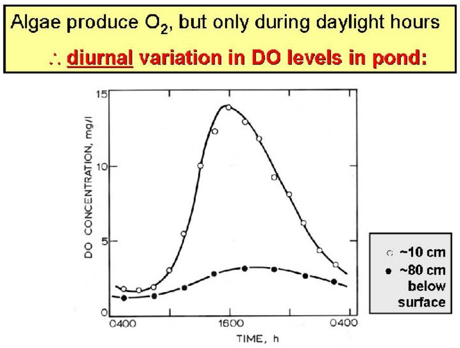
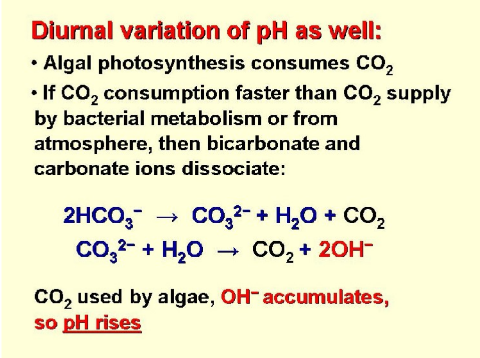
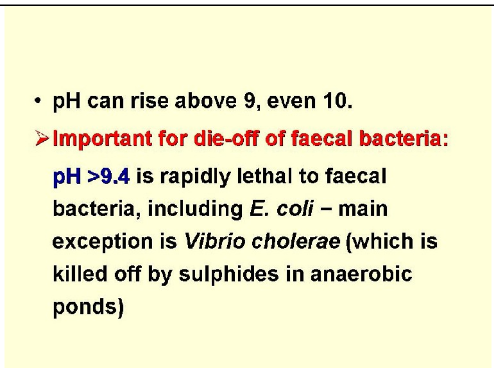
<tr><td></td><td></td><td>BOD is very different from ‘normal’ wastewater BOD, and we’ll come back to this shortly.</td></tr>
<tr><td>5.</td><td>
</td><td>These photomicrographs show some of the algae commonly found in fac. ponds: Chlamydomonas, Chlorella, Euglena and Scenedesmus.</td></tr>
<tr><td>6.</td><td>
</td><td>Algae produce oxygen but only during daylight hours. This means there is a diurnal variation in the dissolved oxygen levels in the pond, and the figure on the slide shows this for two depths, 10 and 80 cm below the pond surface, and you can see that the diurnal variation is much greater at 10 cm than at 80 cm.</td></tr>
<tr><td>7.</td><td>
</td><td>As a result of algal photosynthesis there is a diurnal variation of pH, as well as of dissolved oxygen. This is because when the algae are photosynthesizing rapidly their CO_2 demand exceeds its supply from bacterial metabolism and from the atmosphere, so carbonate and bicarbonate ions in the pond water dissociate to provide more CO_2, but also hydroxyl ions [OH^-], as shown by the equations on the slide. The CO_2 is used by the algae and the hydroxyl ions accumulate, so the pH rises.</td></tr>
<tr><td>8.</td><td>
</td><td>As a result the in-pond pH can rise to above 9 or even above 10, and this is very important for the die-off of faecal bacteria. An in-pond pH of 9.4 and above is rapidly lethal to faecal bacteria, with the exception of Vibrio cholerae which easily tolerates these high pH’s, but fortunately it’s quickly killed by the sulphides in anaerobic ponds.</td></tr>
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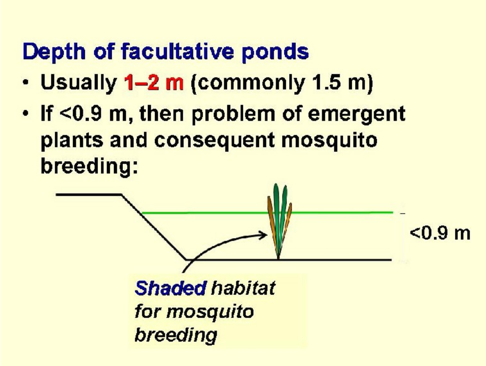
<td>9.</td>
<td>
</td>
<td>The wastewater depth in fac. ponds is somewhere between 1 and 2 m, with 1.5 m being most common. Depths less than 1 m aren’t recommended because there’s the problem of rooted plants growing up through the pond, and they then provide a shaded habitat for mosquito breeding – which we certainly don’t want.</td>
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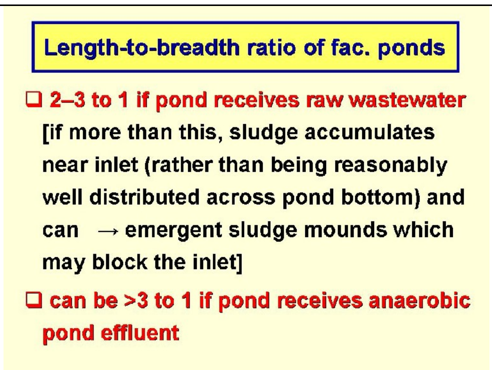
<td>10.</td>
<td>
</td>
<td>The length-to-breadth ratio of primary fac. ponds is 2 or 3 to 1, certainly no more than 3 to 1 as there would be significant sludge accumulation near the inlet, and these sludge mounds can eventually block the inlet.
For secondary fac. ponds the L:B ratio can be greater than 3 to 1, but it shouldn’t be less than 2 to 1.</td>
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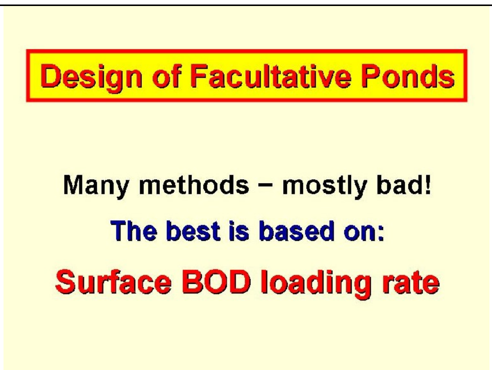
<td>11.</td>
<td>
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<td>So how do we design facultative ponds?

There are quite a few design methods, but few of them are any good. The best is based on surface BOD loading,</td>
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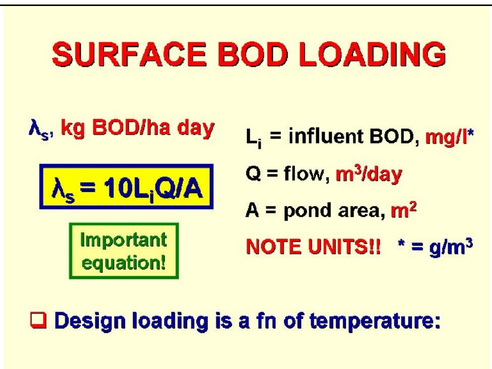
<td>12.</td>
<td>
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<td>which is the amount of BOD applied to the fac. pond surface area per day, and its units are kg BOD per ha per day, and it is denoted by the symbol λ_S.
So, if the influent BOD (L_i) is in mg/l, i.e. g/m^3, the flow (Q) in m^3/day and the area (A), in m^2, then:
$$\boldsymbol{\lambda_S = 10L_iQ/A}$$
We end up with a ‘10’ in this equation as there are 10^3 g in a kg and 10^4 m^2 in a ha.
The value we use for λ_S depends on temperature, the design temperature we’re using.</td>
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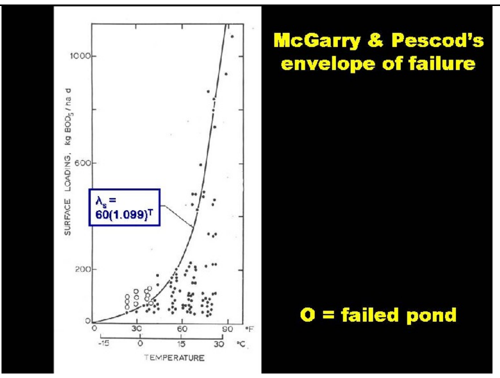
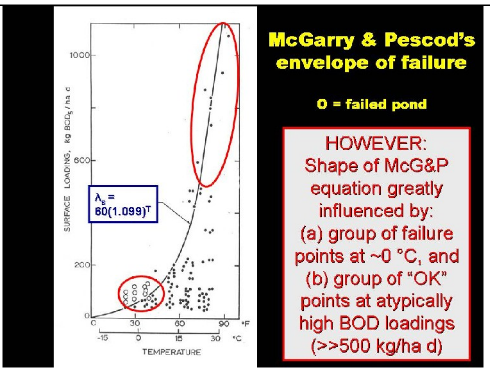
13.	• McGarry and Pescod equation for **maximum** loading rate (ie, **envelope of failure**): $\lambda_s = 10(1.054)^T$ where λ_s is in lb/acre day and T in °F In SI units: $\lambda_s = 60(1.099)^T$ where λ_s is in kg/ha day and T in °C	The McGarry and Pescod equation for the <u>maximum</u> BOD loading rate on fac. ponds is: $\boldsymbol{\lambda_S = 10(1.054)^T}$ where λ_S is in the rather unhelpful units of pounds of BOD per acre per day and T is the design temperature in °F. Using SI units their equation becomes: $\boldsymbol{\lambda_S = 60(1.099)^T}$ where the units are now kg per ha per day and °C.
14.		The McGarry and Pescod equation is really an **envelope of failure**. The figure on the slide shows the data points on which their equation was based: the black dots represent fac. ponds that were working OK, and the open circles represent failed ponds, ponds that had become anaerobic.
15.		However, the shape of the McGarry and Pescod equation is influenced very strongly by the group of failure points around 0°C and the group of reportedly satisfactory ponds operating at very high BOD loading rates, above about 550 kg per ha per day.
16.	• But ponds should not be designed to operate a their point of failure! • Therefore various **design equations** have been introduced • Best is **Mara's global design equation**:	But we don't design ponds to operate at their point of failure, so we can't use the McGarry and Pescod equation for design, but we can use it as a benchmark for a design equation, and the best design equation to use is the Mara global design equation.

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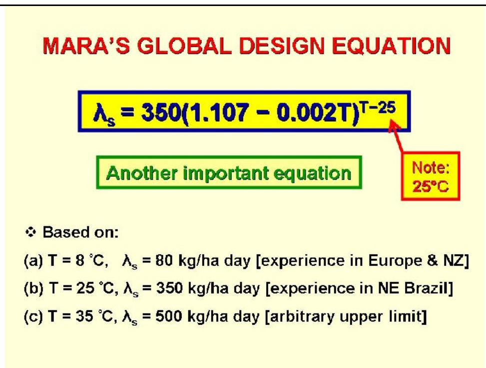
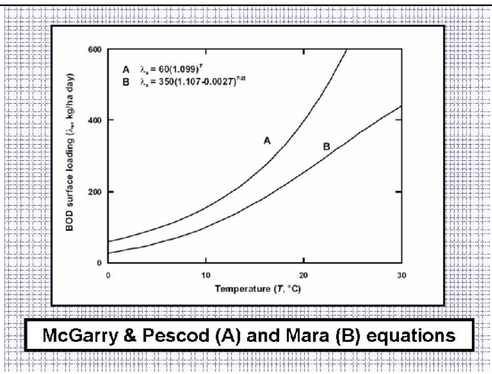
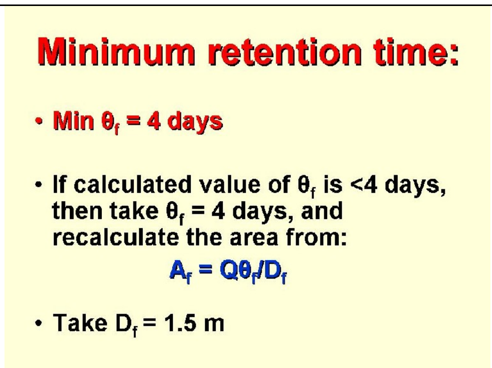
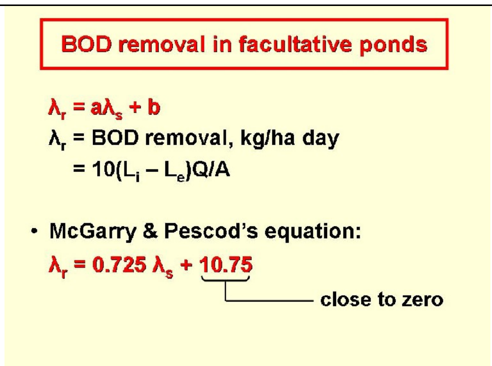
<tr><td>17.</td><td>
</td><td>This states that the design value of λ_S is given by:
$$350 \times (1.107 - 0.002T)^{T-25}$$
In this equation the term raised to, in this case, the power $T-25$ is not a simple Arrhenius constant, but a linear function of T. This was done to make the equation valid over a wide range of temperature, from 8°C to over 30°C, although there are few, if any, places in the world where we would use a design temperature of over 30°C.</td></tr>
<tr><td>18.</td><td>
</td><td>This figure shows the McGarry and Pescod equation and the Mara equation and you can see there's a sufficient factor of safety in the Mara equation at all design temperatures.</td></tr>
<tr><td>19.</td><td>
</td><td>The mean hydraulic retention time, defined as V/Q, in fac. ponds should not be less than 4 days. So if its calculated value is <4 days, we have to use a value of 4 days and recalculate the area, as shown on the slide, assuming a depth of 1.5 m.

[Presentation #7 sets out in detail the fac. pond design procedure.]</td></tr>
<tr><td>20.</td><td>
</td><td>McGarry and Pescod also looked at BOD removal in facultative ponds, and they found that BOD removal expressed in kg per ha per day was a linear function of the BOD loading rate, as shown by the equations on the slide.
Their equation is:
$$\lambda_R = 0.725\lambda_S + 10.75$$
and it's worth noting that the constant 10.75 is in fact close to zero.</td></tr>
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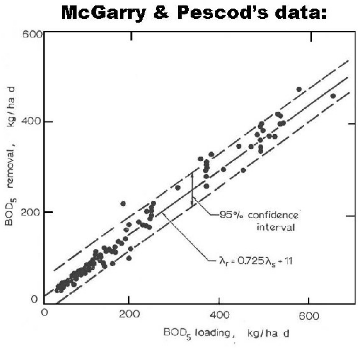
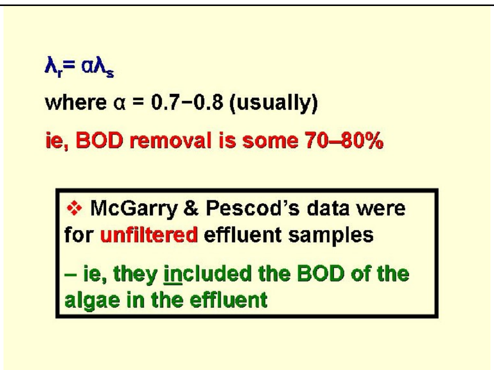
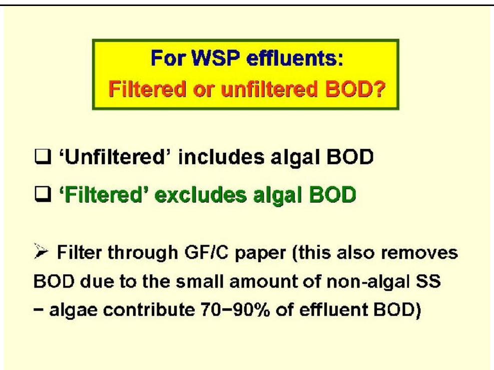
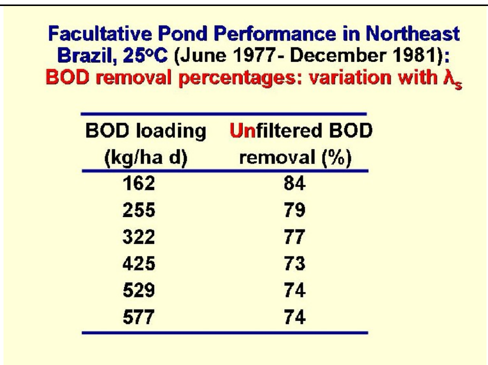
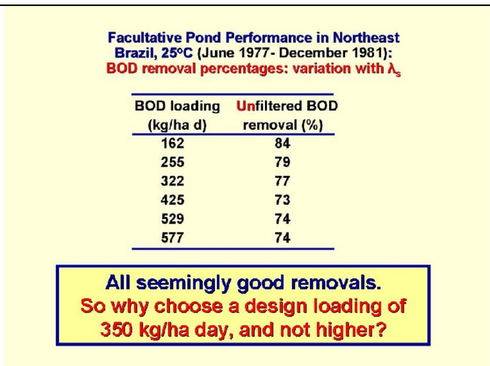
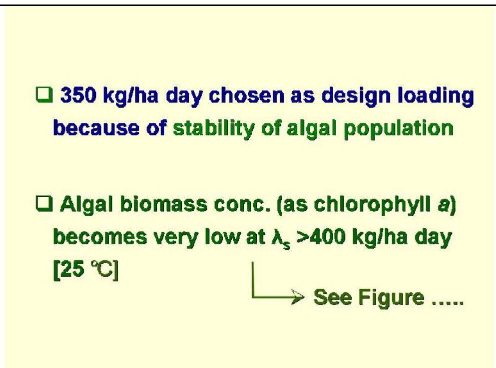
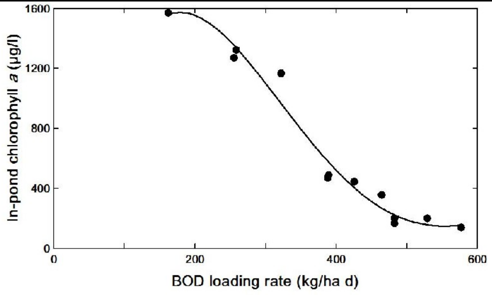
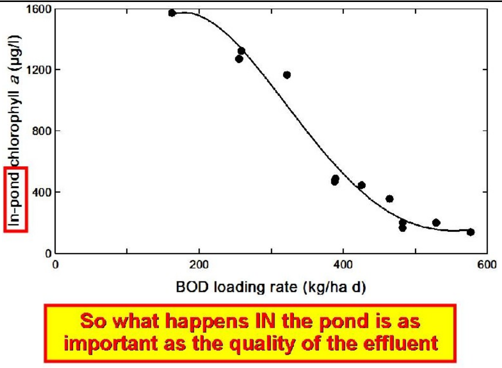
21.		This figure shows the plot of McGarry and Pescod's data. BOD removal in kg per ha per day is on the *y* axis, and BOD loading in the same units is on the *x* axis, and you can see that the linear relationship is a very good one.
22.		We now usually obtain a relationship of the form: $$\lambda_R = a\lambda_S$$ where *a* is somewhere between 0.7 and 0.8 − that is to say, the BOD removal is around 70−80%. The effluent BOD data that McGarry and Pescod used were obtained from **un**filtered samples − i.e., they included the BOD of the algae in the effluents.
23.		This raises the question: should we use filtered or unfiltered BOD for pond effluents? Unfiltered BOD includes the algal BOD and filtered BOD excludes it. We filter the effluent sample using the same filter paper as we use for measuring suspended solids. This will, of course, remove any non-algal suspended solids, but this introduces only a small error as the algae contribute 70−90% of the BOD in pond effluents.
24.		In the European Union the quality of treated wastewaters is governed by the Urban Waste Water Treatment Directive, and this lays down a general BOD requirement of no more than 25 mg/l, but for pond effluents this is **filtered**BOD. Compliance with the Directive's requirement for suspended solids per litre is optional, except for ponds: pond effluents have to have no more than 150 mg suspended solids per litre.

25.		So, we have to ask the question: if this is OK in the European Union, why not in developing countries? This is always something that should be discussed with the local environmental regulator.
26.		This table gives the percentage BOD removals obtained at various BOD loadings, from around 160 to nearly 600 kg per ha per day, on primary facultative ponds in northeast Brazil, at an in-pond temperature of around 25°C.
27.		Now, these percentage BOD removals are all pretty good, so why was a design loading of 350 kg per ha per day chosen for 25°C, and not a higher one?
28.		We chose 350 kg per ha per day as the design loading for 25°C on the basis of the stability of the algal population in the pond, as we found that at this temperature the algal biomass concentration, measured as chlorophyll *a*, became very low when the BOD loading was above ~400 kg per ha per day,

29.		… as shown in these results from our primary facultative ponds in northeast Brazil,
30.		and they tell us that what happens **in** the pond is at least as important as its effluent quality.