International forest eco-hydrological Workshop on Water Management through Forest Management – Contributions towards securing the resources and mitigation of floods –

Dr Mike Bonell

Beijing, November 2007
The Impact Of Tropical Forestation On Soil Hydraulic Conductivity In The Western Ghats, Karnataka and Some Implications On The Runoff Process

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Beijing, November 2007
About 80% of global forestation in the humid tropics is being undertaken by India.

50% of the forestation of India is taking place within the farm-forestry sector of the Western Ghats, India.

SCOPE OF PRESENTATION

Results from a survey of field saturated, soil hydraulic conductivity (K*) across fifteen (15) land covers, and including three (3) soil groups, within the Western Ghats (SE of Goa, Karnataka) will be outlined to investigate the possible impacts of forestation on K*

The determined K* will then be linked with rainfall intensity –duration-frequency (IDF) within three (3) rainfall zones to infer the dominant stormflow pathways.
SCOPE OF PRESENTATION (Continued)

This work was the 1st phase in preparation for the development of hypotheses for an on-going later 2nd phase through the establishment of experimental basins.

Contribution towards the settling the controversial debate (myth?) in the humid tropics:

“does de-(re-)forestation increase (decrease) floods and reduce (increase) low flows?”

in contrast to findings from humid temperate results

Beijing, November 2007
Location of raingauges (by the three rainfall regions) and measurement points of soil hydraulic properties in the study area (Scale 1:1 Million)

Beijing, November 2007
Soil Properties of the test area.

The soils are based on the « Digital Soil Map of the World and Derived Soil Properties » (FAO/UNESCO 2003)

FAO Land and Water Digital Media Series
The Western Ghats escarpment looking south covered by wet evergreen forest
Disk permeameter measurements

Kodgibail soil test site, Siddapur taluk, North Kanara
(Red Soil, Degraded land)

Beijing, November 2007
The field utilization of the disk permeameter on the Jenmury Site at the east of the Western Ghats

Beijing, November 2007
Disk permeameter measurements

Kodgibail soil test site, Siddapur taluk, North Kanara
(Red Soil, Degraded land)

Beijing, November 2007
### Table 1:
The Geology, Soils, Slope Angles, Land Cover and Rainfall at each site

<table>
<thead>
<tr>
<th>Black Soils</th>
<th>Black Soils</th>
<th>Black Soils</th>
<th>Black Soils</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Barchi</td>
<td>Barchi</td>
<td>Ghywee</td>
<td>2.3%</td>
</tr>
<tr>
<td>2 Jemun</td>
<td>Gangavali</td>
<td>Ghywee</td>
<td>2.3%</td>
</tr>
<tr>
<td>3 Kuligi</td>
<td>Thattihalla</td>
<td>Ghywee</td>
<td>2.3%</td>
</tr>
<tr>
<td>4 Thattihalla</td>
<td>Thattihalla</td>
<td>Ghywee</td>
<td>2.3%</td>
</tr>
</tbody>
</table>

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Beijing, November 2007
# Table 1: The Geology, Soils, Slope Angles, Land Cover and Rainfall at each site

<table>
<thead>
<tr>
<th>Site</th>
<th>Geology Soils</th>
<th>Latitudinal/Longitudinal</th>
<th>Slope Angle</th>
<th>Rainfall (mm)</th>
<th>Geology/Soil</th>
<th>Organic Matter Content in High, Shallow (2-3 ft) and Deep (5-7 ft)</th>
<th>Available Phosphorus and Potassium Low/High</th>
<th>Microclimate Optimum</th>
<th>Sub group</th>
<th>Hierarchy</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Amritsar</td>
<td>Afghanistan</td>
<td>15%</td>
<td>0.05</td>
<td>Very clay</td>
<td>Yellowish red, high, matter content in high, shallow (2-3 ft) and deep (5-7 ft)</td>
<td>Available Potassium Low/High</td>
<td>Microclimate Optimum</td>
<td>Amritsar Sub group:</td>
<td>Kharif-Kharif</td>
</tr>
<tr>
<td>6</td>
<td>Patiala</td>
<td>India</td>
<td>2-4%</td>
<td>1</td>
<td>Grey clay</td>
<td>Yellowish red, high, matter content in high, shallow (2-3 ft) and deep (5-7 ft)</td>
<td>Available Potassium Low/High</td>
<td>Microclimate Optimum</td>
<td>Patiala Sub group:</td>
<td>Kharif-Kharif</td>
</tr>
<tr>
<td>7</td>
<td>Amritsar</td>
<td>Afghanistan</td>
<td>2-3%</td>
<td>0.75</td>
<td>Sandy Clay</td>
<td>Yellowish red, high, matter content in high, shallow (2-3 ft) and deep (5-7 ft)</td>
<td>Available Potassium High</td>
<td>Microclimate Optimum</td>
<td>Amritsar Sub group:</td>
<td>Kharif-Kharif</td>
</tr>
<tr>
<td>8</td>
<td>Allahabad</td>
<td>Afghanistan</td>
<td>5.10%</td>
<td>0.5</td>
<td>Mud clay</td>
<td>Dull brown, high, matter content in low, shallow (2-3 ft) and deep (5-7 ft)</td>
<td>Available Potassium Low/High</td>
<td>Microclimate Optimum</td>
<td>Allahabad Sub group:</td>
<td>Kharif-Kharif</td>
</tr>
<tr>
<td>9</td>
<td>Talagadde</td>
<td>Bengal</td>
<td>7-10%</td>
<td>0.5</td>
<td>Dark clay</td>
<td>Brown, high, very low, organic matter content in low, shallow (2-3 ft) and deep (5-7 ft)</td>
<td>Available Potassium Low/High</td>
<td>Microclimate Optimum</td>
<td>Talagadde Sub group:</td>
<td>Kharif-Kharif</td>
</tr>
<tr>
<td>10</td>
<td>Allahabad</td>
<td>Bengal</td>
<td>5-10%</td>
<td>0.5</td>
<td>Clay loam</td>
<td>Yellowish red, high, matter content in low, shallow (2-3 ft) and deep (5-7 ft)</td>
<td>Available Potassium Low/High</td>
<td>Microclimate Optimum</td>
<td>Allahabad Sub group:</td>
<td>Kharif-Kharif</td>
</tr>
<tr>
<td>11</td>
<td>Uttara</td>
<td>Bengal</td>
<td>12-15%</td>
<td>&lt; 0.5</td>
<td>Silty clay</td>
<td>Brown, low, organic matter content in low, shallow (2-3 ft) and deep (5-7 ft)</td>
<td>Available Potassium Low/High</td>
<td>Microclimate Optimum</td>
<td>Uttara Sub group:</td>
<td>Kharif-Kharif</td>
</tr>
<tr>
<td>12</td>
<td>Yettamal</td>
<td>Bengal</td>
<td>3-3%</td>
<td>1</td>
<td>Very clay</td>
<td>Yellowish red, high, matter content in low, shallow (2-3 ft) and deep (5-7 ft)</td>
<td>Available Potassium Low/High</td>
<td>Microclimate Optimum</td>
<td>Yettamal Sub group:</td>
<td>Kharif-Kharif</td>
</tr>
</tbody>
</table>
### Table 1: The Geology, Soils, Slope Angles, Land Cover and Rainfall at each site

#### Red Soils

<table>
<thead>
<tr>
<th>Site</th>
<th>District</th>
<th>Location</th>
<th>Slope Angle</th>
<th>Vegetation</th>
<th>Geology</th>
<th>Land Cover</th>
<th>Rainfall</th>
<th>Soil Type</th>
<th>Sub-group</th>
<th>EC (1989-2000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>Siddepur</td>
<td>Aghanashini</td>
<td>7-8%</td>
<td>Casuarina</td>
<td>Gravelly clay, Yellowish, red, Organic matter content high. Soil is deep.</td>
<td>Gravelly clay, Deep red to red.</td>
<td>Medium acidic. EC normal. Low level of available phosphorus and potash. Micronutrient is moderate.</td>
<td>0.75 - 1.0</td>
<td>Eutric Nitosol</td>
<td>2735 (1989-2000)</td>
</tr>
<tr>
<td>14</td>
<td>Dudmane</td>
<td>Aghanashini</td>
<td>12-15%</td>
<td>Moist Evergreen Natural forest (MEF &amp; OOP)</td>
<td>Gravelly clay. Reddish brown soil. Shallow soil (0.90-1.20m depth). Organic matter content is high.</td>
<td>Gravelly clay. Reddish brown</td>
<td>Soil is acidic. EC normal. CEC very high. Available phosphorus is low and potash is high. Micronutrient level is optimum.</td>
<td>1</td>
<td>Eutric Nitosol</td>
<td>2735 (1989-2000)</td>
</tr>
<tr>
<td>15</td>
<td>Yaliapis</td>
<td>Gangavdi</td>
<td>7-8%</td>
<td>Moist deciduous Forest with Teak as under plantation (MDF with T) (7-8 yr)</td>
<td>Gravelly clay loam. Brown. Organic matter content is high. Soil thickness is deep.</td>
<td>Silty clay, reddish yellow.</td>
<td>Slightly acidic to neutral. EC is normal. Available phosphorus is low and potash is medium. CEC is good. Micronutrients is moderate.</td>
<td>0.75 - 1.0</td>
<td>Eutric Nitosol</td>
<td>2429 (1988-2000)</td>
</tr>
</tbody>
</table>

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Table 2: Rain Intensity (in mmh-1 equivalent)- Duration-Rainfall Frequency (selected return periods are given) (RIDF) estimates for three different rainfall regions.

<table>
<thead>
<tr>
<th>Rainfall Regions with number of raingauges, with station names</th>
<th>Duration</th>
<th>1 yr</th>
<th>2 yr</th>
<th>5 yr</th>
<th>10 yr</th>
<th>25 yr</th>
<th>50 yr</th>
<th>75 yr</th>
<th>100 yr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15 min</td>
<td>50,21</td>
<td>56,39</td>
<td>75,51</td>
<td>88,17</td>
<td>104,16</td>
<td>116,03</td>
<td>122,93</td>
<td>127,81</td>
</tr>
<tr>
<td>Mid-Lands Region</td>
<td>30 min</td>
<td>32,5</td>
<td>39,55</td>
<td>61,37</td>
<td>75,81</td>
<td>94,07</td>
<td>107,61</td>
<td>115,48</td>
<td>121,05</td>
</tr>
<tr>
<td></td>
<td>45 min</td>
<td>26,42</td>
<td>32</td>
<td>49,27</td>
<td>60,71</td>
<td>75,16</td>
<td>85,88</td>
<td>92,11</td>
<td>96,52</td>
</tr>
<tr>
<td>(5 raingauges Mundgod, Bachaniki, Dharma, and Haliyal)</td>
<td>1 hr</td>
<td>21,98</td>
<td>26,57</td>
<td>40,78</td>
<td>50,17</td>
<td>62,06</td>
<td>70,87</td>
<td>76</td>
<td>79,62</td>
</tr>
<tr>
<td></td>
<td>2 hr</td>
<td>13,59</td>
<td>16,59</td>
<td>25,89</td>
<td>32,04</td>
<td>39,81</td>
<td>45,58</td>
<td>48,93</td>
<td>51,31</td>
</tr>
<tr>
<td></td>
<td>3 hr</td>
<td>11,93</td>
<td>13,09</td>
<td>16,71</td>
<td>19,11</td>
<td>22,13</td>
<td>24,38</td>
<td>25,69</td>
<td>26,61</td>
</tr>
<tr>
<td></td>
<td>4 hr</td>
<td>9,57</td>
<td>10,64</td>
<td>13,97</td>
<td>16,18</td>
<td>18,96</td>
<td>21,03</td>
<td>22,23</td>
<td>23,08</td>
</tr>
<tr>
<td></td>
<td>5 hr</td>
<td>8,48</td>
<td>9,41</td>
<td>12,31</td>
<td>14,23</td>
<td>16,66</td>
<td>18,46</td>
<td>19,51</td>
<td>20,25</td>
</tr>
</tbody>
</table>
Log mean field saturated hydraulic conductivity values ($K^*$) using a logarithmic scale, for each of the samples at various depths ( $K^*$ values plotted against the mid-point of the 45-60cm and 120-150cm sampled soil layers).
Log mean field saturated hydraulic conductivity values ($K^*$) using an arithmetic scale, for each of the samples at various depths in Black Soil.
Log mean field saturated hydraulic conductivity values ($K^*$) using a logarithmic scale, for each of the samples at various depths in Lateritic Soils.

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Log mean field saturated hydraulic conductivity values ($K^*$) using an arithmetic scale, for each of the samples at various depths in Red Soils.
Figure.3a. Field saturated hydraulic conductivity, $K^*$ as a function of soil at surface.
Figure 3b. Field saturated hydraulic conductivity, $K^*$ as a function of soil at 0.1m
Figure 3c. Field saturated hydraulic conductivity, $K^*$ as a function of soil at 0.52m
Figure 3d. Field saturated hydraulic conductivity, $K^*$ as a function of soil at 1.35m.
Figure 4a. Field saturated hydraulic conductivity, $K^*$ as a function of depth in Black Soil.
Figure 4b. Field saturated hydraulic conductivity, $K^*$ as a function of depth in Lateritic Soil.
Figure 4c. Field saturated hydraulic conductivity, $K^*$ as a function of depth in Red Soil.
Figure 5a. Field saturated hydraulic conductivity, $K^*$ as a function of land-use at surface.

Field saturated hydraulic conductivity, $K^*$ (mm/hr)

OGF  AcP  Teak (T)  DL  GL

Land-use type

1 in 2 Yr (56.65 mm)
1 in 5 Yr (79.86 mm)
1 in 10 Yr (95.23 mm)
1 in 25 Yr (114.65 mm)
1 in 50 Yr (129.05 mm)
Figure 5b. Field saturated hydraulic conductivity, $K^*$ as a function of land-use 0.1m.
Figure 5c. Field saturated hydraulic conductivity as a function of land-use type.
Figure 5d. Field saturated hydraulic conductivity, $K^*$ as a function of land-use 1.35m
Figure 6a. Field saturated hydraulic conductivity, $K^*$ as a function of depth under old growth forest.
Figure 6b. Field saturated hydraulic conductivity, $K^*$ as a function depth under Acacia plantation.
Figure 6c. Field saturated hydraulic conductivity, $K^*$ as a function of depth under Teak plantation.
Figure 6d. Field saturated hydraulic conductivity, $K^*$ as a function of depth under Grassland.
Figure 6e. Field saturated hydraulic conductivity, $K^*$ as a function of depth under Degraded land.
Figure 7a. Scatter plot of Log mean $K^*$ based on soil group for surface vs 0.1m depth.

<table>
<thead>
<tr>
<th>Soil test site no</th>
<th>Mean $K^*$ at 0.1 m depth (mmh$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1000</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>1000</td>
</tr>
<tr>
<td>6</td>
<td>100</td>
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<td>7</td>
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<td>1000</td>
</tr>
<tr>
<td>14</td>
<td>100</td>
</tr>
<tr>
<td>15</td>
<td>10</td>
</tr>
</tbody>
</table>

Legend:
- Black Soil
- Lateritic Soil
- Red Soil
Figure 7b. Scatter plot of log mean $K^*$ based on land use for surface vs 0.1m depth
Figure 8a. Scatter plot of log mean $K^*$ based on soil group for 0.45-0.60 m vs 1.20-1.50 m depths

Log mean $K^*$ at 1.2 - 1.5 m depth (mmh$^{-1}$)

- Black Soil
- Lateritic Soil
- Red Soil

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Figure 8b. Scatter plot of log mean $K^*$ based on land-use for 0.45-0.60 m vs 1.20-1.50 m depth

- Soil test site no.
- Teak
- Old Growth Forest
- Grass Land
- Acacia Plantation
- Degraded Land
- Casurina Plantation

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Figure 8c. Scatter plot of log mean $K^*$ based on soil group for 0.1 m vs 0.45 – 0.60 m depth.
Figure 8d. Scatter plot of log mean $K^*$ based on land use for 0.1m vs 0.45-0.60m depth

Water Management through Forest Management

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Surface v. 0.1 m depth

Centroid

Median

Ward

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Water Management through Forest Management

0.1 v. 0.45-0.60 m depth

Centroid

Median

Ward

Beijing, November 2007
Water Management through Forest Management

0.45-0.60 v. 1.20-1.50 m depth

Centroid

Median

Ward

Beijing, November 2007
Table 6: Suggested dominant flow paths at each site when comparing the vertical changes in $K^*$ with different rainfall intensity-duration-frequency (RIDF), (15 min to 5 hr) as outlined in Table 2.

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Duration</th>
<th>Return Periods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1yr</td>
</tr>
<tr>
<td>Land Use</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil group</td>
<td>15 min</td>
<td>HOF</td>
</tr>
<tr>
<td>RA R</td>
<td>30 min</td>
<td>VP</td>
</tr>
<tr>
<td>Site 15</td>
<td>45 min</td>
<td>VP</td>
</tr>
<tr>
<td>Yellapur</td>
<td>1 hr</td>
<td>VP</td>
</tr>
<tr>
<td>MDF with T</td>
<td>2 hr</td>
<td>VP</td>
</tr>
<tr>
<td>Red Soil</td>
<td>3 hr</td>
<td>VP</td>
</tr>
<tr>
<td>MID GHAT</td>
<td>4 hr</td>
<td>VP</td>
</tr>
<tr>
<td></td>
<td>5 hr</td>
<td>VP</td>
</tr>
</tbody>
</table>

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Hortonian (infiltration-excess) overland flow

Hortonian (infiltration-excess) overland flow + Subsurface Stormflow (+SOF +RF for certain RIDF)

Vertical percolation + Hortonian (infiltration-excess) overland flow

Hortonian (infiltration-excess) overland flow + Vertical percolation

Vertical percolation

Dominant stormflow pathways

Soil test sites

1. Barchi
2. Jemuri
3. Kuligi
4. Thatihalla
5. Anabebail
6. Patoli
7. Anthrahalli
8. Kolagibees
9. Talagadde
10. Hattikeri
11. Urthota
12. Yettinabail
13. Siddapur
14. Dodmane
15. Yellapur

Beijing, November 2007
Soil test sites
1 Barchi
2 Jemuri
3 Kuligi
4 Thatihalla
5 Anabebail
6 Patoli
7 Anthrahalli
8 Kolagibees
9 Talagadde
10 Hattikeri
11 Urthota
12 Yettinabail
13 Siddapur
14 Dodmane
15 Yellapur

Soil Types using the Indian soil classification system of National Bureau of Soil Survey and Land Use Planning (NBSSLUP) [NBSSLUP Publ. No 47, Soils of Karnataka, Soils of India Series, Shivaprasad et al., 1998] and Land Cover from Karnataka Forest Department (1997)

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CONCLUSIONS

The three Groups of K* determined from Cluster analysis indicated that there is no clear separation between the impacts of land cover vis-a-vis the effect of soil group properties (physical and chemical) on K* within the surface and near-surface horizons.

For the deeper soil horizons (0.45-0.60m; 1.20-1.50m depth), Cluster analysis determined almost the same three Groups i.e. with same site membership, as for surface even though such soil layers are more remote from biological influences. Such consistency indicates that the inherent physical and chemical properties of these soils are more influential on K* than land cover.

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The only clear separation between the Soil Groups in the above classification of $K^*$ are the Black soils (Vertisols) which occupy the least permeable Group I for both the surficial and deeper soil layers irrespective of land cover.

--------The Red soils (Eutric Nitosols) are positioned within the more permeable part of the $K^*$ spectrum.

--------the Lateritic soils (a mixture of Acrisols and Eutric Nitosols) are more complex (probably in response to the complex geology and landforms) and three sub-groupings are suggested.

- The first sub-group occupies the same Group I as the Black soils.
- The second, sub-group of Lateritic soils are more associated with the more permeable Red soils which when combined produces Group II.
- Finally, the third Lateritic sub-group is one site only (Patoli) which acts an outlier of very high permeability and forms Group III.

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There is evidence for forestation using *Acacia* spp over the Lateritic soils in ameliorating $K^*$ at the soil surface ($\leq 0.1\text{m}.\text{depth}$). In contrast, the Casuarinas plantation over the Red soils only has a marginal impact on surface $K^*$ in part due to the dominance of a high permeability regime associated with this soil group.

In contrast, the planting with Teak either in the form of plantations or under planting with existing forest has no significant impact on $K^*$. Further the Black soils have notoriously low $K^*$ under Teak.
The inferred, dominant stormflow pathways for different IDF are nearly aligned with the three $K^*$ Groups. Infiltration-excess overland flow (HOF) is the dominant pathway in the least permeable Group I, and vertical percolation for the most transmissive Group III. The intermediate Group II is transitional and much more complex. It includes all runoff pathways, as well as solely vertical percolation, depending on the rainfall intensity-frequency-duration (IDF) selected.

A persistent message is that forestation (using Teak) over the Black soils does not change the dominant runoff pathway which remains HOF. For the Lateritic soils, and in response to the amelioration of surface $K^*$ by the Acacia and mixed (with Cashew nuts) Plantations; SOF, SSF and RF emerge and add to HOF across the range of IDF.

Acknowledgment: Mr Guillaume Narnio, UNESCO, Division of Water Sciences, 1 rue Miollis, 75732 Paris Cedex 15, France
Overview of Uttara Kannada region with location of blocks and sites

Beijing, November 2007
How do we undertake the necessary scientific research where basin scientific infrastructure is lacking?

A joint IHP-HELP-IAHS(PUB)-FRIEND technical liaison group was established, Oregon State University, November 2005

Beijing, November 2007