EO Information Services
in support of
Monitoring of Water Quality and
Land Use Changes in the
Lake Titicaca Basin

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World Bank HQ, Washington DC
World Bank Meeting

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  - First Analysis of Results
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Introduction
The EOWORLD Initiative

Collaboration of the European Space Agency (ESA) and World Bank

- Innovative satellite Earth Observation services to Bank’s operations / Exploration of utility (Aim)
- Initiative started in 2008
- Led by World Bank FEU Department, based on ESA pro bono support

- 15 pilot projects implemented across the SDN:
  - Disaster Risk Management
  - Urban Development
  - Agriculture and Forest Management
  - Water Resources Management
  - Coastal Zones Management
  - Marine Environment Management
  - Climate Change Adaptation

Go to www.worldbank.org/earthobservation for details!
Lake Titicaca
- located in the Andes on the border of Peru and Bolivia
- largest lake in South America by volume
- 3812m above sea level (Altiplano)
- total shoreline length of 1125km
- RAMSAR site
- Service area: 47 000km²
Background: The World Bank Project

Reason/ driver for this information
- Lack of reliable data on water parameters (no mechanism for systematic data collection)
- Need for consistent Land Use data for authorities and policy makers (cross boundary)

Project information requirements
- Information concerning lake water quality (e.g. nutrient concentrations, pollution, turbidity, ...), water plant monitoring (e.g. Algae blooms)
- Land use change information (focusing on wetland /crops)
- Timeliness: January 2012 (Input for the State of the Lake Report)

Project goal
- Support of definition, planning, implementation, monitoring and assessment of the related WB project
Land Use Change Service
Product specifications

Land Use Change Information
- Land Use 2010
- Land Use 2003
- Land Use Change 2010-2003

Satellite Missions processed:
- LANDSAT: 7 scenes in 30m resolution from 2003
- RapidEye: 11 scenes in 5m resolution, 2010/2011.

Provided product formats:
- GeoTif: product includes geographical information and the concrete value or concentration for each pixel
- PDF print: ArcGIS map export, printing all relevant information in an easy accessible pdf format
Coverage 2010:

RapidEye
- German constellation of five identical EO satellites
- Optical system, 5m spatial resolution
- 5 spectral bands
Coverage 2010 detail view:

**Agricultural Production**
**Umachiri, Peru**
Coverage 2010 detail view:

**Urban Structure**
**City of Juliaca, Peru**
Coverage 2003:

**LANDSAT**
- Constellation of 2 EO satellites (TM5 and ETM7)
- Optical system, 30m spatial resolution
- 7/8 spectral bands
13 thematic classes:

Legend:
- Forest
- Major Agricultural Surface Types
- Settlements
- Primary Roads
- Bare Soil
- Water Bodies
- Rivers
- Wetlands
- Shrub/Grasslands
- Clouds
- Snow
- Burned Areas
- Totora Reeds
- Conservation Areas
- Lake Titicaca sub-basin
Lake Titicaca Sub-Basin: Land Use Map 2010

Land Use Map of Lake Titicaca sub-basin covering 47,000 km² (total area including Lake Titicaca). Based on recent satellite data from 2010. The classes represent the detected land use/land cover within a semi-automatic approach.

**Projection**
WGS 1984 UTM Zone 19S
1:1,200,000

**EO Data**
11 RapidEye Scenes
Acquisition dates:
2010-07-23, 2010-08-02, 2010-08-07, 2010-08-16, 2010-08-17, 2010-09-27, 2010-09-15, 2010-10-04, 2010-11-13, 2010-12-14, 2011-04-14

**EOWorld Initiative**
EOWorld project supported by the German Ministry of Economic Cooperation and Development (BMZ) under Contract ID 844K1319, within the framework of the program "Monitoring of Water Quality and Land Use Changes in the Lake Titicaca Basin (MOWQ-LTB)". The project is carried out under the responsibility of GAF AG & BAV GmbH, Germany.
Land Use Statistics 2010

### Area in km² and Percentage

<table>
<thead>
<tr>
<th>No.</th>
<th>Class Name</th>
<th>Area in km²</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Forest</td>
<td>39.66</td>
<td>0.08</td>
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<tr>
<td>2</td>
<td>Major Agricultural Surface Types</td>
<td>9059.09</td>
<td>19.19</td>
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<tr>
<td>3</td>
<td>Settlements</td>
<td>112.24</td>
<td>0.24</td>
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<td>4</td>
<td>Primary Roads</td>
<td>272.16</td>
<td>0.58</td>
</tr>
<tr>
<td>5</td>
<td>Bare Soil</td>
<td>23724.35</td>
<td>50.26</td>
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<tr>
<td>6</td>
<td>Water bodies</td>
<td>8053.71</td>
<td>17.06</td>
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<tr>
<td>7</td>
<td>Rivers</td>
<td>176.67</td>
<td>0.37</td>
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<tr>
<td>8</td>
<td>Wetlands</td>
<td>288.23</td>
<td>0.61</td>
</tr>
<tr>
<td>9</td>
<td>Shrub/Grassland</td>
<td>4745.79</td>
<td>10.05</td>
</tr>
<tr>
<td>10</td>
<td>Clouds</td>
<td>2.20</td>
<td>0.00</td>
</tr>
<tr>
<td>11</td>
<td>Snow</td>
<td>205.94</td>
<td>0.44</td>
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<tr>
<td>12</td>
<td>Burned Areas</td>
<td>115.59</td>
<td>0.24</td>
</tr>
<tr>
<td>13</td>
<td>Totora Reeds</td>
<td>404.29</td>
<td>0.86</td>
</tr>
<tr>
<td></td>
<td><strong>Total Area</strong></td>
<td><strong>47199.93</strong></td>
<td><strong>100.00</strong></td>
</tr>
</tbody>
</table>
Land Use Map 2003

Lake Titicaca sub-basin: Land Use Map 2003

Legend:
- Forest
- Allen Vegetation in its Natural Type
- Deforested
- Protected Areas
- Water Bodies
- Water Bodies
- Wetlands
- Riparian Areas
- Clusters
- Roads
- Gas and OIl Areas
- Water Resources

Interpretation:
Land Use Map of Lake Titicaca sub-basin covering 47,080 km² (total area including Lake Titicaca). Based on historic satellite data from 2003. The classes represent the detailed land and land cover within a semi-automatic approach.

Projection:
WGS 1984 UTM Zone 19S
1:1,000,000

EO Data:
- LandSat ETM+ Scores
- LandSat 7 ETM+ Scores
  Acquisition date: 2003-05-25

EOWORLD Initiative:
EO World Initiative is a global initiative and enables the benefits of EOs for a sustainable future within the context of the United Nations Agenda 2030, the Sustainable Development Goals (SDGs) and the sustainable development of the planet. EOWORLD Project and Contractor: MONITORING OF WATER QUALITY AND LAND USE CHANGES IN THE LAKE TITICACA BASIN

GAFAG
THE WORLD BANK

esa
Land Use Statistics 2003

<table>
<thead>
<tr>
<th>No.</th>
<th>Class Name</th>
<th>Area in km²</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Forest</td>
<td>33.33</td>
<td>0.07</td>
</tr>
<tr>
<td>2</td>
<td>Major Agricultural Surface Types</td>
<td>8732.40</td>
<td>18.50</td>
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<td>3</td>
<td>Settlements</td>
<td>100.76</td>
<td>0.21</td>
</tr>
<tr>
<td>4</td>
<td>Primary Roads</td>
<td>310.32</td>
<td>0.66</td>
</tr>
<tr>
<td>5</td>
<td>Bare Soil</td>
<td>23267.95</td>
<td>49.29</td>
</tr>
<tr>
<td>6</td>
<td>Water bodies</td>
<td>8856.48</td>
<td>18.76</td>
</tr>
<tr>
<td>7</td>
<td>Rivers</td>
<td>171.25</td>
<td>0.36</td>
</tr>
<tr>
<td>8</td>
<td>Wetlands</td>
<td>203.22</td>
<td>0.43</td>
</tr>
<tr>
<td>9</td>
<td>Shrub/Grassland</td>
<td>4419.11</td>
<td>9.36</td>
</tr>
<tr>
<td>10</td>
<td>Clouds</td>
<td>366.79</td>
<td>0.78</td>
</tr>
<tr>
<td>11</td>
<td>Snow</td>
<td>326.02</td>
<td>0.69</td>
</tr>
<tr>
<td>12</td>
<td>Burned Areas</td>
<td>101.38</td>
<td>0.21</td>
</tr>
<tr>
<td>13</td>
<td>Totora Reeds</td>
<td>318.38</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td><strong>Total Area</strong></td>
<td><strong>47207.40</strong></td>
<td><strong>100.00</strong></td>
</tr>
</tbody>
</table>
Land Use Change Map

Lake Titicaca sub-basin: Land Use Change Map 2010/2003

Interpretation
The legend displays classes with at least 2% area change. White areas are indicated as no-change within the land use.
The proportionally largest land use changes are located at the shoreline, clearly indicating the recorded water levels of Lake Titicaca within the time period covered.

Projection
WGS 1984 UTM Zone 19S
1:1,200,000

EO Data
- Landsat 5 TM Scenes & 1 Landsat 7 ETM+ Scene
  - Acquisition Dates: 2003-07-08, 2005-08-06, 2009-12-15
- RapidEye Scenes

EO WORLD Initiative
EO WORLD is an open-source, dynamic, multimedia platform designed to democratize Earth Observation data and knowledge. It is a global initiative that provides access to EO data, services, and tools to support research, education, and applications in various fields. The platform promotes transparency, collaboration, and innovation in the use of EO data for scientific, societal, and commercial purposes. More information is available at www.eoworld.info.

EO WORLD Project and Contractor
EO WORLD is a joint initiative of the World Bank and the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt, DLR) to support the development and dissemination of an open-source platform for Earth Observation data and knowledge. The project is funded by the European Commission through the Copernicus Programme.
Land Use Change Overview entire AoI

- Forest 2003
- Major Agricultural Surface Types 2003
- Settlements 2003
- Primary Roads 2003
- Bare Soil 2003
- Water Bodies 2003
- Wetlands 2003
- Shrub/Grassland 2003
- Clouds 2003
- Snow 2003
- Burned Areas 2003
- Totora Reeds 2003
- Forest 2010
- Major Agricultural Surface Types 2010
- Settlements 2010
- Primary Roads 2010
- Bare Soil 2010
- Water Bodies 2010
- Wetlands 2010
- Shrub/Grassland 2010
- Clouds 2010
- Snow 2010
- Burned Areas 2010
- Totora Reeds 2010
Monitoring results for the Lake Titicaca sub-basin: Years 2003-2010:

- **The size of Lake Titicaca has decreased**
  (-650km² / -7%)

- **The shoreline has significantly changed**
  (1661km to 1552km / more than 100km)

- **Main changes in Land Use in close proximity to the Lake Titicaca**

- **Former wetland and reed areas are now used for agricultural purposes**
Example:

Puno Bay, Peru
Example:
Puno Bay, Peru
Reserva National - Titicaca

2003

2010
<table>
<thead>
<tr>
<th>Class Name</th>
<th>Area in km²</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
<td>2003</td>
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<tr>
<td>Forest</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Major Agricultural Surface Types</td>
<td>17.854</td>
<td>0.270</td>
</tr>
<tr>
<td>Settlements</td>
<td>0.011</td>
<td>0.006</td>
</tr>
<tr>
<td>Primary Roads</td>
<td>0.034</td>
<td>0.006</td>
</tr>
<tr>
<td>Bare Soil</td>
<td>63.101</td>
<td>0.286</td>
</tr>
<tr>
<td>Water Bodies</td>
<td>62.521</td>
<td>284.884</td>
</tr>
<tr>
<td>Rivers</td>
<td>1.634</td>
<td>0.003</td>
</tr>
<tr>
<td>Wetlands</td>
<td>38.508</td>
<td>0.288</td>
</tr>
<tr>
<td>Shrub/Grassland</td>
<td>26.110</td>
<td>0.217</td>
</tr>
<tr>
<td>Clouds</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Snow</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Burned Areas</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Totora Reeds</td>
<td>149.474</td>
<td>73.271</td>
</tr>
<tr>
<td>Total:</td>
<td>359.247</td>
<td>359.231</td>
</tr>
</tbody>
</table>

Reserva National - Titicaca
Water Quality Service
Water Quality Information
- Turbidity in [NTU]
- Suspended Matter in [mg/l]
- Phytoplankton Chl-a in [μg/l]

Satellite Missions processed:
- ENVISAT MERIS: 50 scenes, 300m resolution, 2003 – 2010
- MODIS Aqua and Terra: 13 scenes, 500m resolution, 2004/2011

Provided product formats:
- GeoTif: quantative concentrations, geographical information
- ArcGIS map: integrates the GeoTif with legend and additional information layers
- PDF print: ArcGIS map export, print of all relevant information
Liability: values in designated shallow water areas should be treated with care
Total Suspended Matter [mg/l]

27 March 2003
Chlorophyll a
27 March 2003
Liability: values in designated shallow water areas should be treated with care.
High temporal resolution 11. – 21. Jun’04
Multi-sensor compatibility

11.06.04
MERIS

12.06.04
MODIS

14.06.04
MODIS

15.06.04
MERIS

16.06.04
MODIS

17.06.04
MODIS

18.06.04
MODIS Terra

18.06.04
MODIS Aqua

19.06.04
MODIS Terra

19.06.04
MODIS Aqua

20.06.04
MODIS

21.06.04
MERIS
Seasonal trends of Chlorophyll a
Comparison with ground truth

Seasonal trends are plausible in space and time.
Seasonal trends are plausible in space and time.

Central Lake Titicaca

Seasonal trend of Chlorophyll a

Comparison with ground truth

Satellite retrieved concentrations

In situ campaign 26.5.-30.5.2003

Coordinate: UTM E 448272 N 8269015, +/- 1200m
Central station 123 Entre Islas Soto y Taquile
MERIS data 2003 - Sept. 2011, EOMAP processor MIP

Chlorophyll a [µg/l]

Month

Seasonal trend of Chlorophyll a

Central Lake Titicaca

Seasonal trend of Chlorophyll a

Satellite retrieved concentrations

In situ campaign 26.5.-30.5.2003

Coordinate: UTM E 448272 N 8269015, +/- 1200m
Central station 123 Entre Islas Soto y Taquile
MERIS data 2003 - Sept. 2011, EOMAP processor MIP

Chlorophyll a [µg/l]

Month
Validity:
Consistent and plausible concentrations in space and time, estimated accuracy 0.5 µg/l Chl and 0.5 mg/l TSM

Restrictions:
Overestimation for TSM and Chl a in optical shallow waters, for Chl a also in inflows with increased dissolved organic matter

Strength:
- Harmonized monitoring worldwide
- Flexible in terms of required spatial and temporal resolution, using various satellite resources
- NRT service available for selected satellites
Getting started: How to work with WQ products

Analysis of spatial and temporal features
- Evaluation of anthropogenic and natural impacts:
  Impact of river inflows, catchment areas
- Seasonal and multi-annual trends

Virtual monitoring stations:
- Products: Easy to understand, continuation with known WQ measurements
- Implementation of quality measures for each observation
- Easy implementation into operational monitoring programs
- No dependency on single satellite missions

Understanding and getting used
Provision of short user guides and support
- to visualize, read, understand, interpret products
- to analyse time series
- to implement service into operational monitoring programs
- to compare and evaluate aquatic systems worldwide
Service Benefits
Service benefits for the Lake Titicaca sub-basin:

- Recent, objective, cross border information on Land Use and Land Use Change around Lake Titicaca
- Harmonised Water Quality Monitoring with high temporal solution
- High spatial resolution EO data (5m) as baseline data for various planning tasks
- Standardised information layers and map products, ready for GIS import and further analysis
- Identification of spatial development trends through Change Detection analysis between 2003 and 2010
- Cost efficient mapping for 47 000 km²

Expected Impact

- Valuable information & input for the The State of the Lake report
- Recent information on spatial development for various local stakeholders in Bolivia and Peru
- Supplementary/ independent information for the running WB project
The EO Service Providers

Basic facts:
- Private sector company, located in Munich, GERMANY
- 26 years of professional experience in applied earth observation
- Today ~160 staff members

Specialised in:
- EO data reception, distribution and value adding
- Geo-information services and applications
- International project consulting (>500 projects)

Clients:
- International Agencies
  (EU, ESA, FAO, UN, WEU, ...)
- International Development Banks
  (WB, IDB, Asian & African DB, EuropeAid, ...)
- National authorities
  (Federal & regional ministries, KfW, GTZ, ...)
- Private sector
  (consulting, media, construction, oil & gas, telecommunication, mining, insurers/re-insurers, ...)

(Riviered GAF projects)
Basic facts:
- Independent SME, located in Gilching, near Munich, GERMANY
- Approx. 10 highly specialized experts with either Masters or Doctorate degrees

Specialised in:
- Customized, large-area mapping based on satellite and airborne imagery for a manifold of applications with a focus on aquatic remote sensing and automated image processing.

Clients:
- International Organisations
  (Research Executive Agency of the European Commission REA, European Space agency ESA, ...)
- National authorities/ government
  (German Aerospace Center DLR, Federal Waterways Engineering and Research Institute BAW, Federal Institute of Hydrology BfG, ...)
- Private sector
  (Oil- and Gas industry, offshore construction in Australia, Netherlands, UAE, US, ...)
Thank you

Questions & Discussion

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Thomas.Heege@eomap.de