Rapid Hydrological Appraisal (RHA) of Singkarak Lake in the context of Rewarding Upland Poor for Environmental Services (RUPES)

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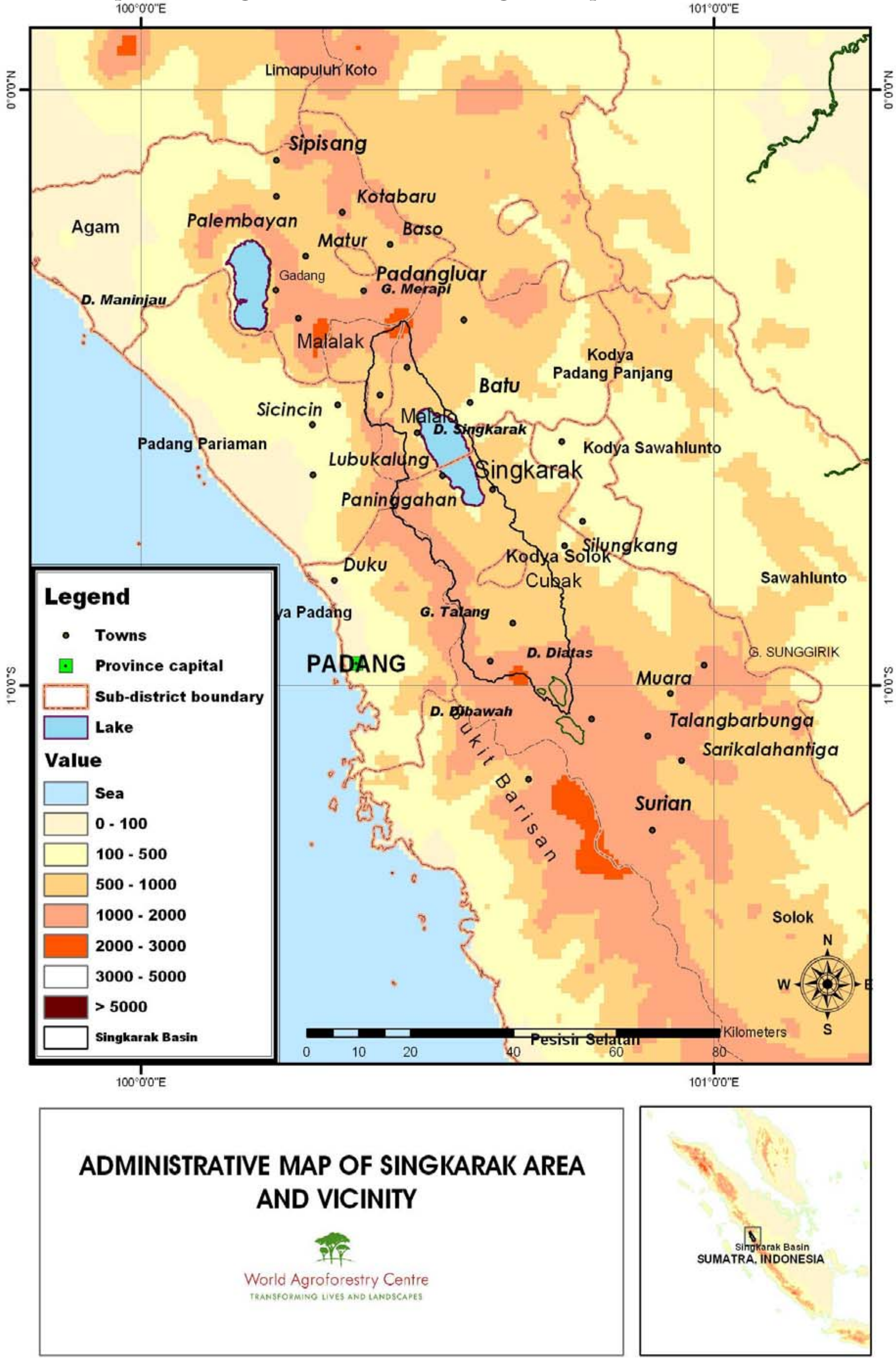
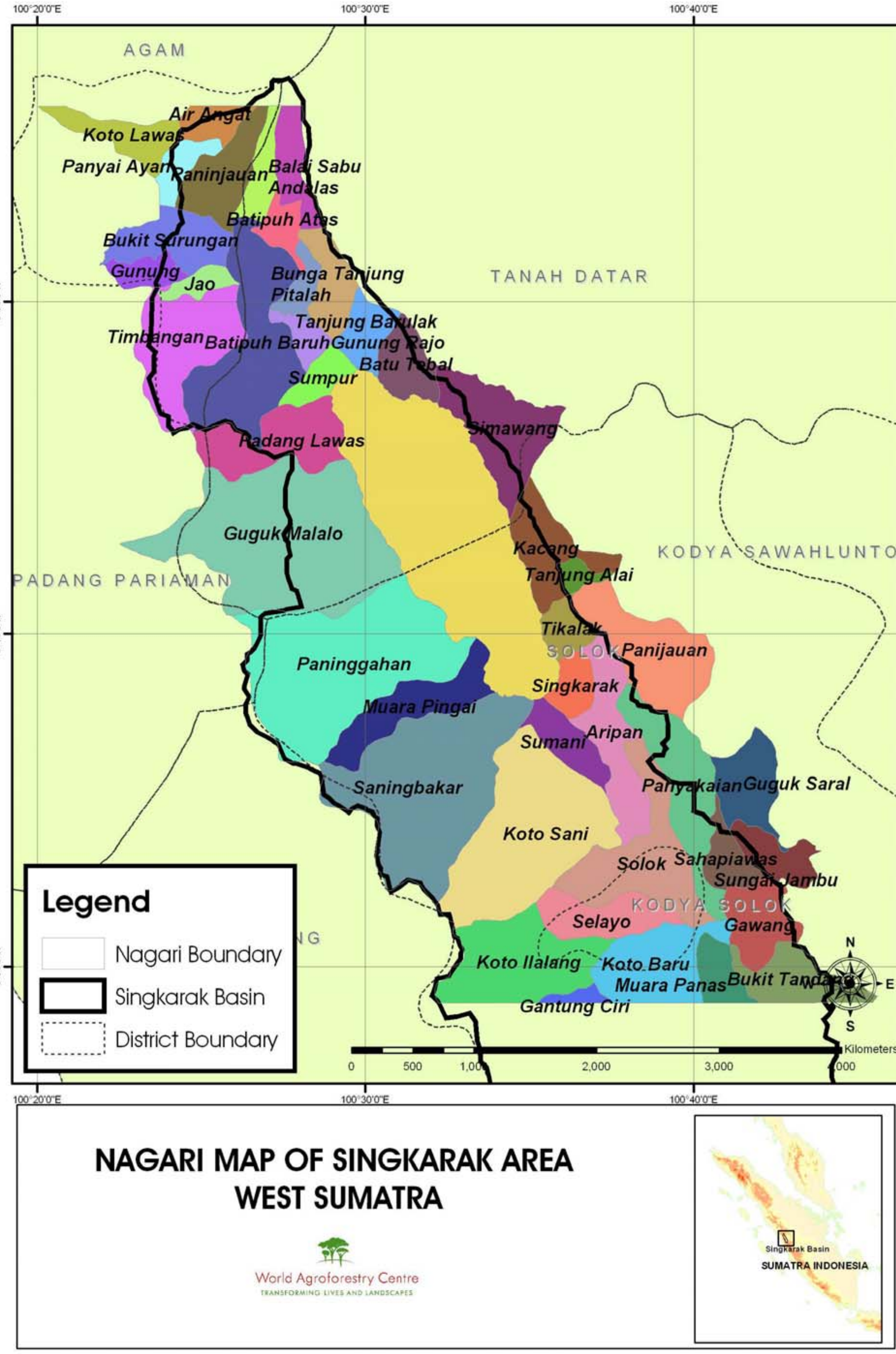
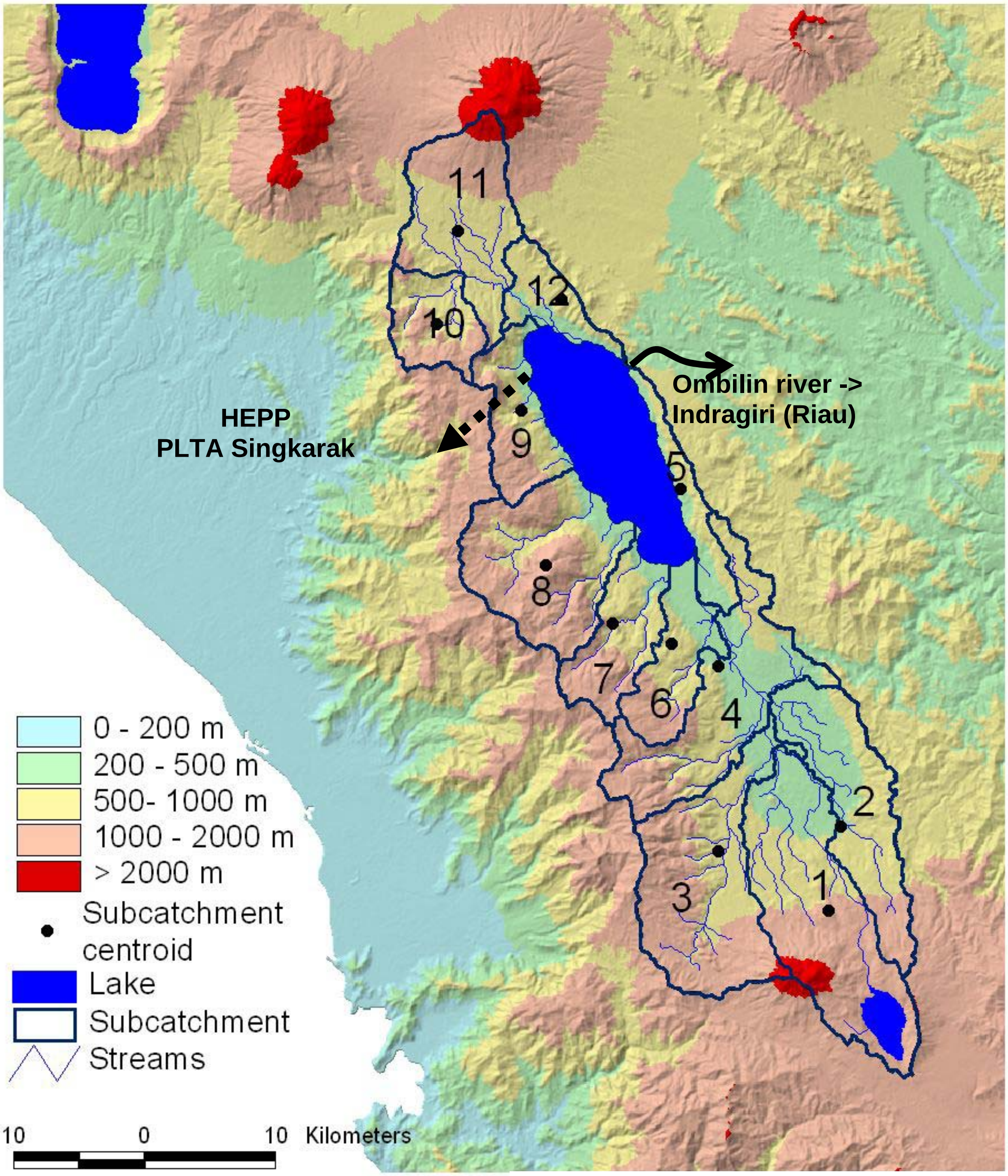
Map 1. Lake Singkarak and the surrounding landscape in West Sumatera



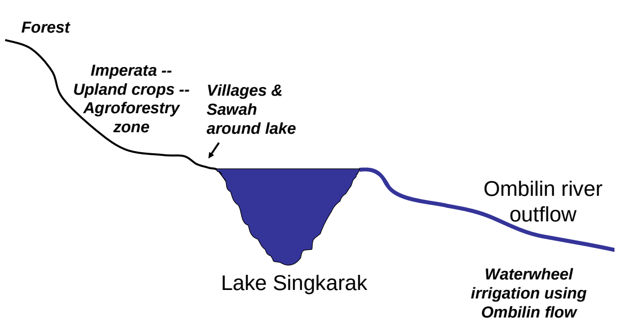
Map 2. Administrative (Nagari) map in the vicinity of Singkarak Basin



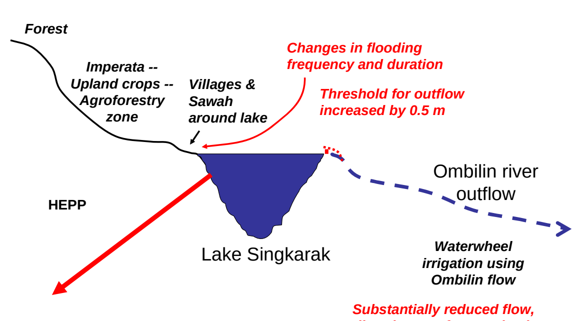
Map 3. Subcatchments in the Singkarak basin



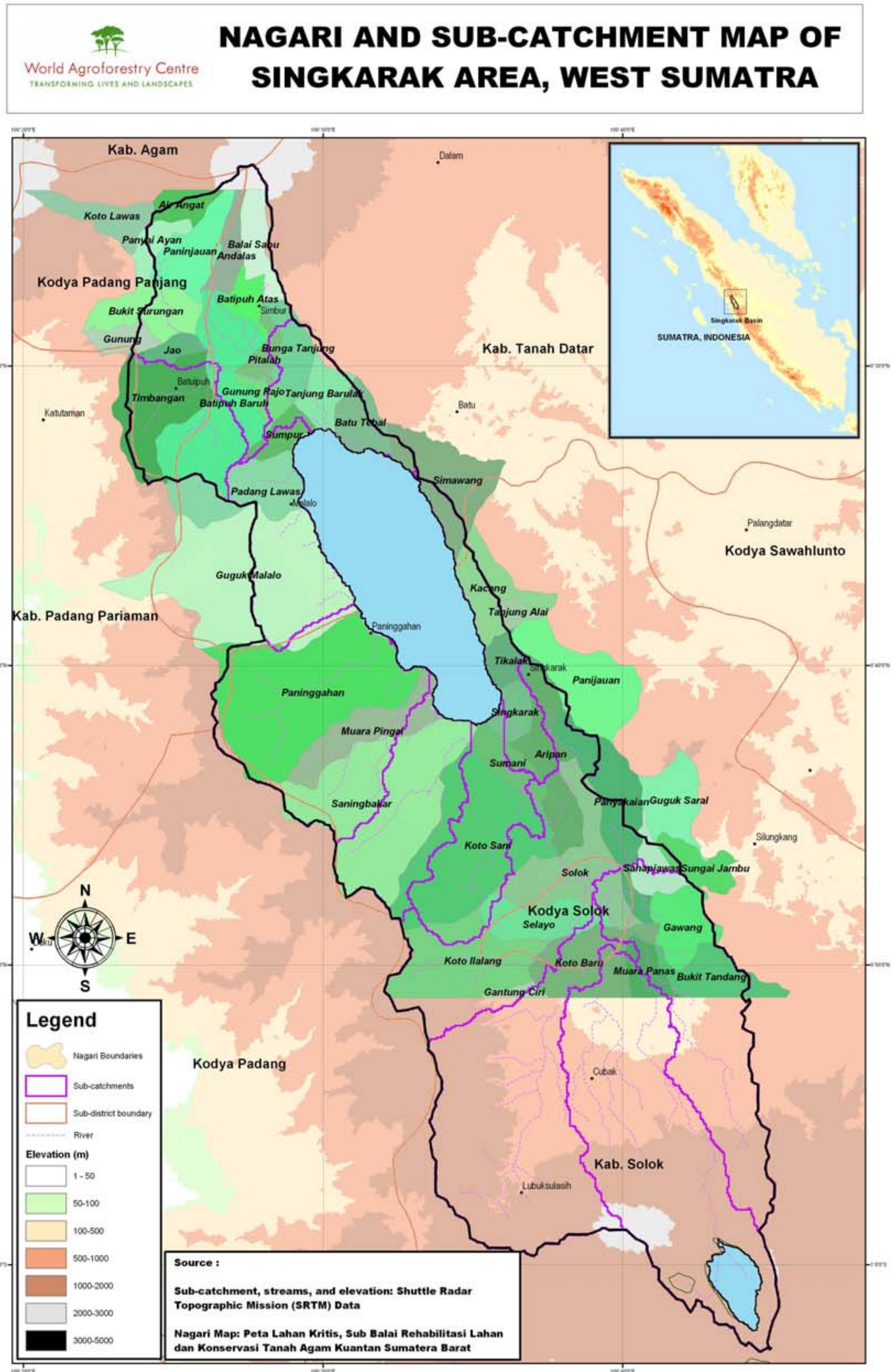
Situation before Hydro-Electric Power Plant (HEPP)



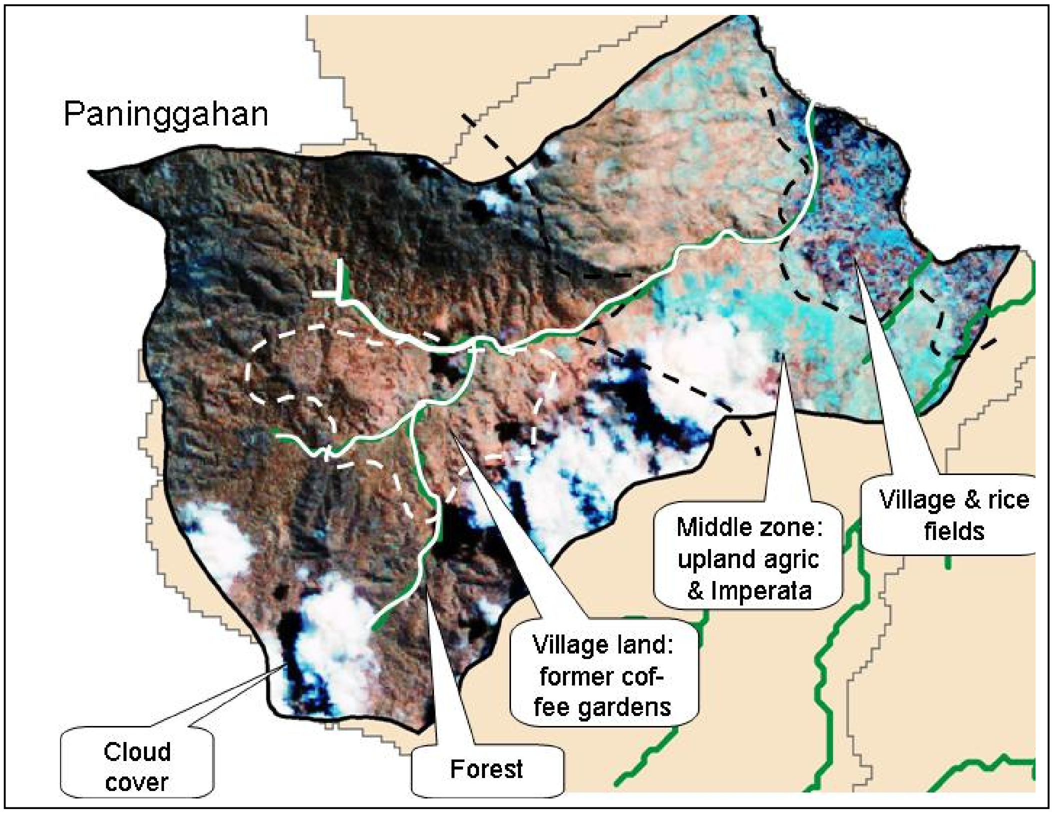
Situation after Hydro-Electric Power Plant (HEPP)

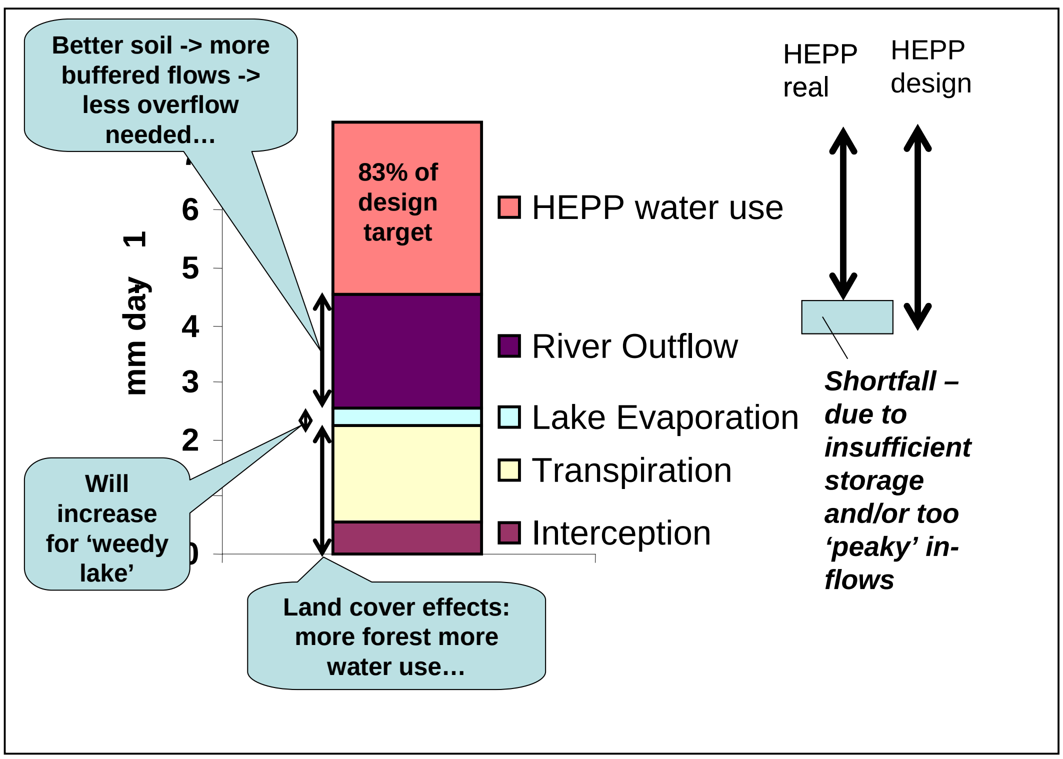


Masp 4. Nagaris and subcatchments in the Singkarak basin



Map 6. Detail of Landsat image of Nagari Paningahan





Executive summary

This report presents results of a 'rapid appraisal', during a 6-months period of the hydrological situation in the Singkarak Basin in West Sumatera (Indonesia) in the context of the development of payments for environmental services (ES) that are aimed at rewarding the upland poor for protection and/or rehabilitation of watershed functions.

The main 'issue' that became the focus of the study is the relationship between the hydroelectricity project (HEPP, PLTA Singkarak), the fluctuations in the level of the lake, the water quality in the lake and the land cover of the catchment areas that contribute water to the lake. Payments made by the PLTA to the local government can, in part, be seen as rewards for maintaining or improving environmental services. The *Nagari* of Paningahan, almost coinciding with one of the lakeside subcatchments has become an action research site for the RUPES project to test the modalities of ES reward schemes. In the discussions on the topic it became evident that there is no full and shared understanding of the relationships between land cover and the 'environmental services' provided.

The assessment (within a relatively short time frame, with a focus on cost-effectiveness) was based on five components:

- Search of the literature and web-based resources on the area and initial 'scoping' meeting with key stakeholders,
- Spatial analysis of the landscape based on remotely sensed imagery and available maps and digital data,
- Exploration of local ecological knowledge of the landscape, water movement and consequences of land use options,
- Discussions with a wide range of stakeholders and policy makers on issues of land use and hydrological functions,
- Modeling of the water balance and water use in the landscape to explore scenarios of plausible land cover change and their likely impacts on key performance indicators with the GenRiver model.

The major land cover types in the Singkarak Basin are rice fields (17%), agricultural crops (15%) and forest (15%). Rice fields occur in the lowland area, below 1000 m asl and with the slopes of < 30%, commonly found in the southern part of the basin, around Solok, and in smaller extent in the area north of the lake, around Simbur/Padang Panjang. The underlying substrate of thess areas are alluvium for those in the south and breccia in the north, but both are originally from andesite volcanic material. Besides rice, other types of agricultural crops are also found in the lowland plain around Solok to the south around Cubak/Mt Talang up to > 1000 m asl. In this higher elevation area, the crops are mostly vegetables, having long been the main cultivation in the area. Other land cover types like mixed gardens , coconut-based mixed garden, shrubs and grass are found in smaller patches all over the basin. In the higher elevation (> 1000m asl) and where slopes are steeper (>30%) along the western range of the basin -- parts of Bukit Barisan-- and in the upslope of Mt Merapi, forest is the dominant land cover type. Patches of pine forest are found in Bukit Barisan range above Paninggahan and Batuipuh.

The main conclusions of the consultations are that there is broad agreement on '***objectives***' such as the need to maintain a clean lake, productive landscapes on hills and irrigated plains that meet the expectations of the high population density as well as produce electricity for the provinces of West Sumatera and Riau.

There is a widely held perception that the current landscape is ***not*** meeting all these expectations: the PLTA is not able to provide as much electricity as was expected, the fluctuations in the level of the lake are a concern to the people surrounding the lake, the water quality of the lake is a concern, the population of the endemic fish (ikan bilih) is declining and

previous efforts to rehabilitate the Imperata grassland (alang alang) in the area have not been very successful.

Much of the debate is focused on ***proposed solutions*** and especially on the relative merits of 'reforestation' and the various alternative ways to achieve 'land rehabilitation'. While for many policy makers reforestation, either using the local *Pinus merkusii* or other fast growing tree species is the main approach, villagers in Paninggahan are convinced that streams dry up in the dry season after reforestation with pine trees, while the natural forest is providing regular stream flows. The water balance model with the default parameter values for Pine tree confirmed a higher water use by canopy interception and transpiration compared to more open landscapes, but no substantial difference with natural forest. Impacts of land cover via soil properties may need to be further tested. Further hydrological distinctions between the limestone and granite parts of the landscape are needed as well

Overall the ***water balance model*** suggested that the possible performance of the PLTA is only mildly influenced by land cover within the range of scenarios tested. Compared to the current land use mosaic an increase of 5% or a decrease of 5% of the maximum electricity production can be expected, while the variation between 'wet' and 'dry' years of the 1991-2002 period is much larger. Details of PLTA lake management matter a lot. A change in mean annual rainfall under the influence of global climate change will have a strong effect on PLTA performance. Declining water quality in the lake leading to weed infestation will offset any gains in water supply that could result from 'land degradation'. Reforestation with fast growing evergreen trees will have a mildly negative effect on water usable by the PLTA.

A basic assumption for 'payments for environmental services' is that the supply of these services does depend on activities of those 'rewarded'. For the PLTA this assumption is not supported by much evidence….Payments made by the PLTA may have various types of rationale:

- Compensation for damage caused by the HEPP project, to the farmers along the Ombilin river whose waterwheel irrigation systems are disturbed and to farmers with rice fields surrounding the lake affected by increased flooding
- Shared responsibility for maintaining the water quality in the lake as the HEPP project modified outflow rates and increases debris accumulation
- Payments of tax to local government
- Goodwill enhancing payments to the local community
- Payments for environmental services conditional to the delivery of these services

At this stage the evidence for the last component is relatively weak, and almost absent for the scale level of ***avoided degradation*** in a single nagari. Efforts of all lake-side nagari's will be needed to deal with the issues of lake water quality, while rehabilitating the other inflows to the lake need at least equal attention.

1. Introduction

1.1. Why Rapid Hydrological Assessment (RHA) and Rupes

Concerns over loss of tropical forest, are based on the loss of 'intrinsic value' of forests, but also for the loss of environmental service functions. Land use mosaics that include forest areas, agriculture and agroforestry, may still provide important parts of these environmental service functions, but the direct benefits that upland land users derive do not reflect these functions. Maintaining or enhancing these functions thus remains an 'externality' to the decision making. Mechanisms that link lowland beneficiaries to upland land use decisions through appropriate reward mechanisms may provide a cost effective way to enhance sustainable development. The RUPES ('Rewarding Upland Poor for the Environmental Services they provide') consortium in which ICRAF, IFAD, IUCN, CIFOR, CI, FF, WWF and other international partners work together with national partners in (currently) Indonesia, Philippines, Vietnam, China, Thailand, India and Nepal is supporting a network of 'action research sites' and 'national policy review' activities to facilitate such mechanisms. Specific attention is given to 'pro-poor' forms of ES reward mechanisms. Benefits to poor people can come both through the way rewards are channeled and the positive environmental impacts of the decisions they support.

In the context of reward mechanisms for forest-derived environmental service functions, 'watershed functions' in a broad sense are likely to be the most urgent, direct and marketable aspect of upland land use. Biodiversity protection may be eligible for higher rewards per person in specific areas and increasing terrestrial carbon stocks may have captured the imagination of many policymakers, but watershed functions are prominent in the public perception.

The generic term '***watershed functions***' means different things in different situations, to different stakeholders. After a century of attention for 'watershed management' there is still a remarkable lack of clear criteria and indicators of the hydrological functions that society expects to be met from water catchment areas. Hydrological functions of watersheds, given the rainfall that the area receives and its underlying geology and land form, include the capacity to

1. Transmit water,
2. Buffer peak rain events,
3. Release water gradually,
4. Maintain water quality and
5. Reduce mass wasting (such as landslides).

The relation between full ('forest') and partial ('agroforestry') tree cover and hydrological functions in this sense involves changes at different time scales, and tradeoffs between total water yield and the degree of buffering of peak river flows relative to peak rainfall events. More realistic expectations of quantitative indicators for historical baseline, current situation and plausible future scenarios may help the negotiations (especially based on difference between current situation and a range of plausible scenarios for change). The appreciation of the various quantitative indicators probably differs by stakeholder group and need to be understood from the perspective of 'local – upland', 'local – lowland', 'public – policy' and 'ecology – hydrology' to facilitate the negotiation process.

1.2. Lake Singkarak as RUPES action research site

Number of people living surrounding Singkarak Lake is about 399.095 people or about 205 people per km^2 (Dephut, 2002) and about 42% with age of between 18 and 55 years old. About 10% of the population lives under the poverty line and about 4,559 families are shifting cultivators covering about 10,624 ha of shifting cultivation ('open-field cropping in a fallow rotation') area. The main source of income of the people is agriculture and fishery (76.5%). An endemic fish species of the lake called '*ikan bilih*' which is famous for human consumption has been harvested at a rate of more than sustainable rate. The population of '*ikan bilih*' is now decreasing. Deforestation also increases and this will create more unproductive lands such as grasslands and critical lands particularly in steep areas.

In the popular press the perception of a logical link between loss of forest cover, problems with the level of the lake and decline in fish production is commonly expressed. The area deforested has increased over time. The water level of the Singkarak Lake can drop by up to 2 meters in dry periods. Under this condition, the electricity generators (PLTA Singkarak) are functioning on less than the intended capacity and 'black outs' can not be avoided. During dry periods farmers also face shortfalls in irrigation water, and the intention to grow three crops of rice per year can not be realized in every year. At present, water from the Singkarak Lake provides irrigation water for rice paddy area located in Kabupaten Solok, Padang Pariaman, Tanah Datar and Sawahlunto Sinjunjung. While, the PLTA Singkarak provides most of electricity demand of two Provinces, i.e. West Sumatera and Riau Provinces (about 986 GWH per year). The popular perception is that several of these problems are caused by 'deforestation' and that forms of 'reforestation' may revert the 'environmental degradation' that has taken place. The financial benefits from undisturbed electricity production are potentially high enough to justify paying a share of them to the 'providers of environmental services' who can maintain and restore the environment…. That at least, was the start of interest in a RUPES action resea4rch site around Lake Singkarak.

Although there have been various earlier efforts to reforest the critical land surrounding Singkarak Lake, success has been very limited. After 1998, there are no significant land rehabilitation projects taking place at Singkarak Lake. Now the total area of 'critical land' is about 18.664 ha (Pemda Sumbar, 2002). As the community is more aware of the importance of forest cover on Singkarak Lake, they have started to reforest and rehabilitate the critical and degraded forest, even though at low rate. The local community surrounding Singkarak Lake has done many small-scale rehabilitation activities using agroforestry system. The activities were conducted under the coordination of *Wali Nagari* (Head of Village). After the 'reformasi' change in government in 1998, the West Sumatera Government has given more authorities to local governments (up to village level or *Nagari*) to manage their resources without much intervention. And this encourages the *Nagari* to make their own initiative to manage and rehabilitate their own resources. One of the initiatives which is now underway, is a rehabilitation program called a Million Trees Panting Program (*Penanaman Sejuta Pohon*). This program was started in February 2003 at Junung Sirih sub-district, Kanagarian Paningahan. It was targeted that about 540 ha of the critical land will be rehabilitated every year. This program will be carried out for five years to cover about 2700 ha of critical land. Up to know total area that has been rehabilitated by the community using community fund was only 30-40 ha. Without support from other funding, it might difficult for local community to reforest all the critical lands.

Indonesia government has now ratified the Kyoto Protocol and is establishing a Designated National Authorities (DNA) for *Clean Development Mechanisms* (CDM). These efforts are to allow Indonesia to participate in CDM projects. Carbon benefits generated by the CDM projects, such as carbon sequestration projects through afforestation and reforestation, can be sold or purchased by developed countries. Thus, the communities who participate in reforestation and afforestation projects under this mechanism will get income from selling the carbon. From the National Strategy Studies on Clean Development Mechanism conducted by the Ministry of Environment, Singkarak Lake has been identified as one of the potential site for the implementation of forest-carbon projects. The local stakeholders at Singkarak Lake have shown their interested in CDM projects as this mechanism could provide additional funding to support the land rehabilitation program. The local government also showed their interest to this mechanism, as this mechanism may be one of the potential funding sources to accelerate the degraded land/forest rehabilitation program.

Rewarding the local community for the environmental services that they provided (RUPES) will encourage them in maintaining their natural resources and assist them in accelerating the rehabilitation program. However, such reward system is not well established. At present, the regulations that relate to this issue are Undang-Undang Number 34/2000 on Tax for Surface and

Sub-Subsurface Water (*Pajak Air Permukaan dan Bawah Tanah*) and Government Regulation Number 65/2001 on Regional Taxation (*Pajak Daerah*). For implementing this regulation, the local government has issued Local Government Regulation or PERDA Number 4/2002 on Tax for Utilization of Surface and Sub-Subsurface Water (*Pajak Pemanfaatan Air Permukaan dan Bawah Tanah*). According to this PERDA, the allocation of the tax money would be 30% for Provincial Government, 35% for the district that produce the tax, and 35% for other districts of West Sumatera Province. However, further regulation on how this tax should be used or distributed to the community is not available. For this year, water tax collected from PLTA Singkarak was about 2.2 billion rupiah (250 thousands US$) and about 777 million rupiah (88.3 thousand US$) has been distributed to Solok and Tanah Datar districts. Wali Nagaries expect that most of this tax should be given directly to local community through Nagari and therefore they also requested the district governments to issue a regulation on tax distribution.

On the other hand, the institutional system at local level to facilitate the implementation of the above regulation is not available. However, the initiative to establish such system is now underway. The community surrounding Singkarak Lake represent by the Wali Nagaris, Heads of Kabupaten Solok and Tanah Datar Districts, and representatives from the Local House of Representative (*Komisi D DPR Provinsi*), has conducted a meeting on 1st April 2003 to discuss the institutional system for coordinating all the development process at Singkarak Lake. It was agreed in the meeting that such institution should be formed and it would be named as Management Body for Singkarak Lake (*Badan Pengelola Danau Singkarak*). Series of meetings to discuss the formation of the Body as well as role and its function will be held. It is expected this body could play important role in establishing rewarding system for the upland poor who provide the environmental services.

1.3 Recognition and reconciliation of three types of knowledge

In discussions between upland and lowland land users, public policy and science, three types of 'knowledge' (local, public and scientific) are interacting, often expressed in languages that have little in common and using concepts that may be considered 'myths' in other domains. Where negotiations between multiple stakeholders are an essential part of any RUPES mechanism, clarity is needed on what 'ES function' is the focus, how it is provided, who can be (or claim to be…) responsible for providing this service, and how rewards can be channeled to effectively enhance or at least maintain the function.

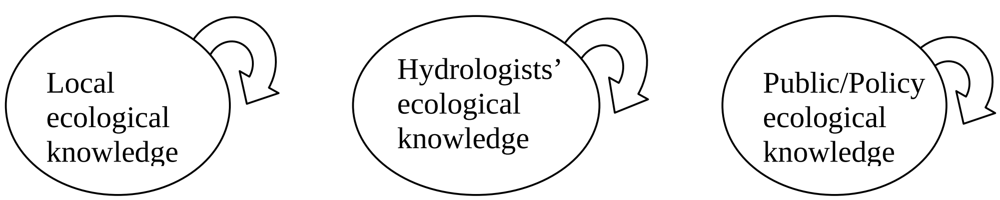


Figure 1.1. Current situation: three poorly connected knowledge systems

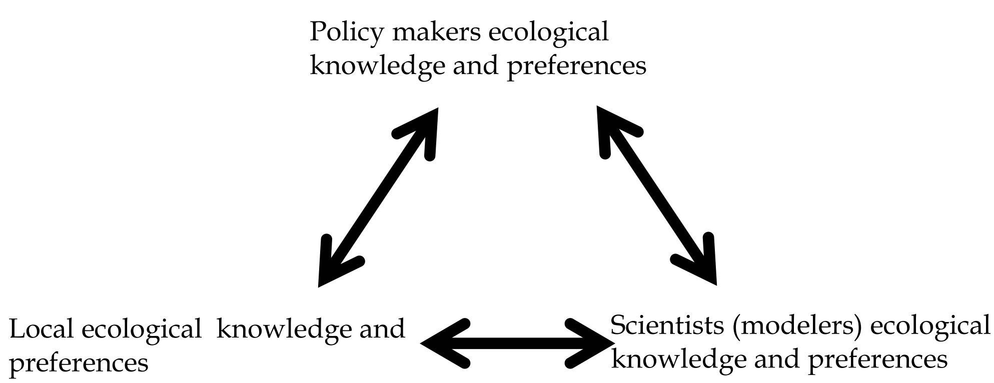


Figure 1.2 Desirable situation where the three knowledge domains are connected and interact

1.4 Steps in RHA

The main objectives of the RHA:

1. Understand local land use patterns, the benefits it provides to actors in the landscape, the alternative land use options that exist and the current drivers of change.
2. Understand the impacts of local land use change on environmental services, and thus on potential 'buyers' that are willing to provide incentives to maintain or enhance specific services.

The RHA is targeted the 'scoping' stage of the process to get buyers and sellers to talk to each other.

The main RHA activities are:

1) **Stakeholder analysis (who is involved, affected) within physical river basin ('ridge to reef') and ranking of their criteria.** This activity starts with a geographic identification of the river basin, search of relevant documents and literature, discussion with key informants. Depending on the number and diversity of the stakeholders identified and an assessment of their interactions, one or more group consultations are set up to list and rank problems and start with the analysis of perceptions on cause and possible cure for the problems.

Stage	Providers, sellers of environmental services	Intermediaries	Beneficiaries, buyers of environmental services
Scoping	➢ What do we have that is of interest to outside stake-holders? ➢ What are the downsides to us of efforts to conserve/ enhance the service? ➢ What are the positive sides to us of maintaining watershed functions? ➢ What 'willingness to pay' can we expect?	'Rapid ES assessment tools' Develop common understanding, criteria & indicators	➢ Where are the areas/ communities controlling the most urgent conservation needs? ➢ Who is effectively controlling these areas? ➢ What 'willingness to enhance & conserve' can we expect for what price? ➢ Is it worth it for us?
Identifying partners	➢ Who should we talk to? ➢ What documentation or '***projectization***' do we need?	Brokerage Reduce transaction costs	➢ Who can effectively represent all local 'actors'?
Negotiations	➢ How do we balance restrictions imposed on us with substantive rewards?	Process support Living examples	➢ How do we know we can trust the 'sellers'? ➢ What guarantees are built in?
Monitoring agreement	➢ How can we deal with defectors & free riders in the community? ➢ How do we know the buyer is satisfied?	Monitoring, evaluation, audit	➢ What guarantees are built in? ➢ How are 'compliance' (at output level) & outcome monitored?

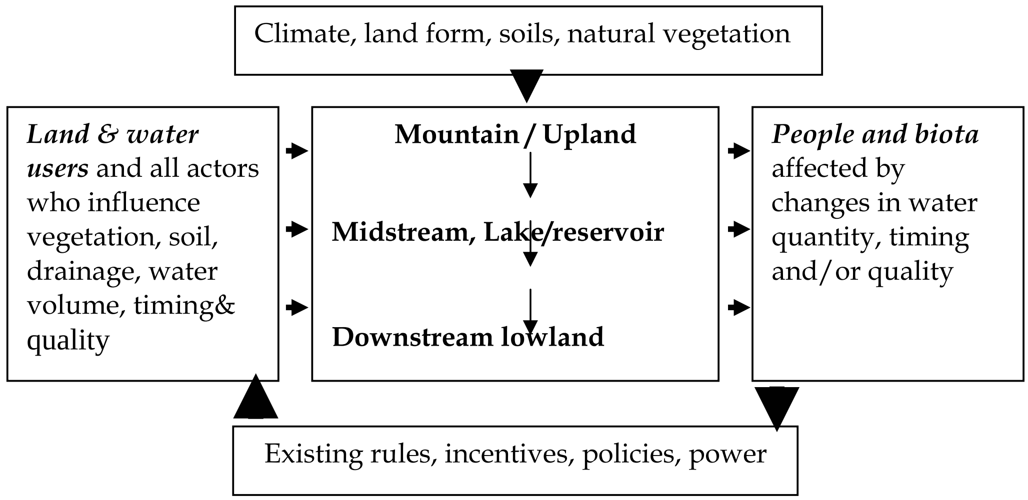


Figure 1.3 Some key relationships between the hydrological performance of a watershed, the human drivers and impacts of land use change

2) **Local ecological knowledge (LEK) documentation and analysis**
Local ecological knowledge (LEK) of forests, landscapes with partial tree cover, water, riverflow and water quality will be explored, documented and evaluated using the knowledge-based systems approach originally developed at the University of Wales (Bangor, UK) and previously applied in various sites in Indonesia. We will stratify by relevant ethnic, gender and wealth categories. The methodology allows explicit articulation and analysis of knowledge of women and other disadvantaged communities. Non-ecological knowledge (such as cultural beliefs and obligations, religious taboos) will also be documented from local communities. Local level training-cum-workshops on knowledge acquisition and analysis will be conducted for field staff. The full representation of local knowledge will be shared and discussed within the group, before it is compared to the knowledge of others. Depending on resources and time available, this step can be done in rapid (quick scan) mode in 2-3 weeks, or in a thorough mode, requiring several months of fieldwork. Tools for solliciting 'Local scenarios' exist.

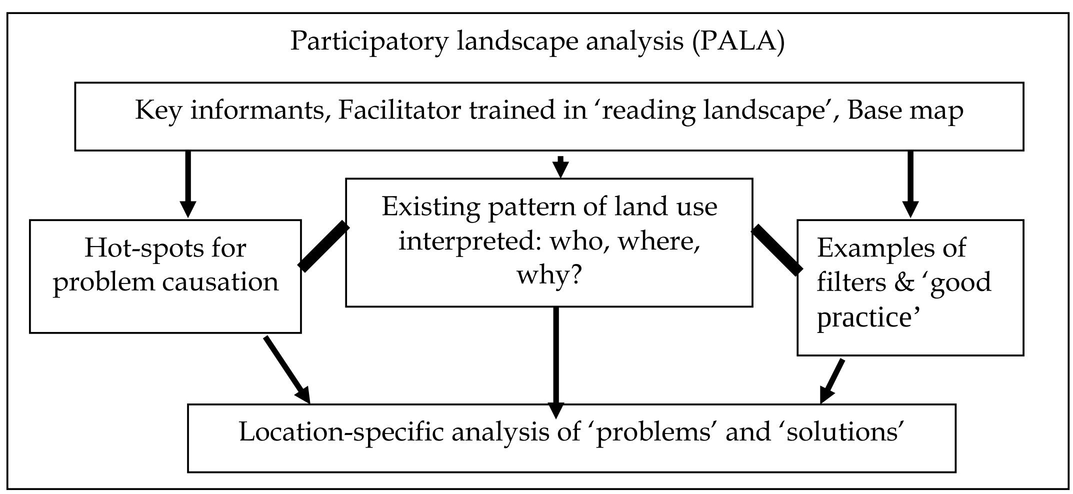


Figure 1.4 Steps in participatory landscape analysis and exploration of (explanatory) local ecological knowledge

3) Public & policy-shapers ecological knowledge (PEK) documentation &analysis

Hydro-ecological knowledge of government officials, downstream stakeholders and the (urban) general public (PEK) in all study sites will be explored. Individual interviews with representatives of the these stakeholders will be conducted adopting the same approach as used in the LEK documentation and analysis.

4) Spatial analysis

To support the overall context as well as, more particular, for RHA, geospatial data collection, processing and analyses need to be conducted in integrated and comprehensive manners. However, in line with the concept of 'rapid' assessments, as much as possible secondary data are opted and processing of raw data should be done applying practical methods, but still ensuring the optimum quality of the information produced.

5) Modeler/Scientist ecological knowledge (MEK) documentation and analysis

Use of a water balance model to relate rainfall data and various scenarios for land cover and land use to the predicted inflows to the lake and availability of water for the hydroelectricity turbines. Comparisons between scenarios (with varying degrees of forest cover) can clarify the 'environmental services' provided through land use patterns, above a baseline of 'degraded' soils and landscape condition.

2. Material and Methods

2.1 Compilation of documents on the study area

A literature study and review was made by searching the appropriate document of Singkarak area in the internet and visited the related various agency in West Sumatera.

List of literature available at internet :

No	Title	Author	Source	Year
1	Special Evaluation Study on the Social and Environmental Impact of Selected Hydropower Project	ADB	www.**adb**.org/Documents/PERs/SS-36.pdf	1999
2	Water Management in the Upper Sub-basin of Indragiri River Basin in Indonesia : Issues and Implications Related to Integrated Water Resources Management	Helmi (Unand)	http://www.iwmi.cgiar.org/pubs/Proceedings/Loskop/sectionD.pdf	2000
3	Water Accounting for Conjuctive Ground Water/Surface Water Management : Case of Singkarak-Ombilin River Basin, Indonesia	Natalia Peranginangin, et.al		
4	Recreating the Nagari : Decentralization in West Sumatera	Franz Und Keebet, et.al	http://www.eth.mpg.de/dynamic-index.html?http://www.eth.mpg.de/pubs/wps/mpi-eth-working-paper-0031.html	2001
5	Buku Panduan Sosialisasi UU no 22/1999 tentang Otonomi Desa	PNT, SfDM, PRODA-NT	http://www.gtzpromis.or.id/Proda/documents/Buku_Panduan.pdf	2001
6	Danau Singkarak Kini Jadi Sumber Masalah	Kompas	http://www.kompas.com/kompas-cetak/0306/09/teropong/197053.htm	2003

7	Air Danau Singkarak Kritis	Kompas	http://www.kompas.com/kompas-cetak/0306/09/teropong/326061.htm	2003
8	PLTA Singkarak Harus Diaudit Lingkungan	Kompas	www.kompas.com/kompas-cetak/0009/06/nasional/**plta**20.htm	2000
9	PLTA Singkarak Selalu Disalahkan	Kompas	http://www.kompas.com/kompas-cetak/0306/09/teropong/197062.htm	2003
10	Sumatera Barat Rawan Bencana, Lahan Kritis 175.000 Ha	Kompas	http://www.kompas.co.id/kompas-cetak/0312/27/daerah/768991.htm	2003
11	Air Dikuras, Daerah Tangkapan Air Diabaikan	Kompas	http://www.kompas.com/kompas-cetak/0204/22/daerah/aird25.htm	2002

List of literature from various agencies in West Sumatera :

No	Title	Source	Year
1	Komunikasi ilmiah pengembangan tanaman industri dan perkebunan pada lahan kritis sekitar danau Singkarak – Sumatera Barat	Pusat Penelitian dan Pengembangan Tanaman Industri dengan Badan Perencanaan Pembangunan Daerah Sumatera Barat	1990
2	Pengumpulan data dan informasi kualitas lingkungan hidup daerah tangkapan air (DTA) Danau Singkarak Kabupaten Solok	Dinas Pertambangan dan Lingkungan Hidup Kabupaten Solok dengan Pusat Studi Lingkungan Hidup Universitas Andalas Padang	2003
3	Buku keterangan peta satuan lahan dan tanah lembar Padang (0715) Sumatera	Pusat Penelitian Tanah dan Agroklimat – Badan Penelitian dan Pengembangan Pertanian	1990
4	Buku keterangan peta satuan lahan dan tanah lembar Solok (0815) Sumatera	Pusat Penelitian Tanah dan Agroklimat – Badan Penelitian dan Pengembangan Pertanian	1990
5	Laporan akhir kebijakan pengelolaan plasma nutfah ikan bilih endemik untuk kelestarian alam dan pembangunan berkelanjutan di danau Singkarak	Badang Perencanaan Pembangunan Kabupaten Tanah Datar dengan Lembaga Penelitian dan Pengabdian Masyarakat Universitas Bung Hatta Padang	2001
6	Pengelolaan Danau di Sumatera	Badan Pengendalian Dampak Lingkungan Wilayah I Sumatera	2000
7	Survey Report : Waterhyacinth (Eichhornia crassipes) Solms and water quality in Kerinci, Maninjau and Singkarak Lakes, Sumatera	Directorate General of Forest Protection and Nature Conservation, Asia Wetland Bureau - Indonesia	1992
8	Laporan tahunan dinas pertanian kabupaten solok	Dinas Pertanian Kabupaten Solok	2002
9	Materi bimbingan teknis, monitoring dan evaluasi GNRHL Kabupaten Solok tahun 2003/2004	Dinas Kehutanan dan Perkebunan Kabupaten Solok	2004
10	Singkarak hydro scheme project	Asian Development Bank	1990
11	Laporan profil kawasan KTP2D	Departemen Permukiman dan Prasarana	2003

	(Kawasan Terpilih Pusat Pengembangan Desa) Kawasan Nagari Paninggahan	Wilayah Sumatera barat dengan CV Harrisa Consultant	
12	Survey potensi sumberdaya alam dan masyarakat selingkar Danau Singkarak	PLN Sektor Bukittinggi dengan Lembaga Pengabdian Masyarakat Universitas Andalas - Padang	2003
13	Laporan akhir : Penyusunan rencana pengelolaan DAS terpasu DAS Danau Singkarak	Departemen Kehutanan Propinsi Sumbar dengan PT Andalan Unggul Konsultan	1995
14	Petunjuk pelaksana Program water management PLTA Singkarak	Tim Evaluasi, penyempurnaan dan Monitoring Water Management PLTA Maninjau dan PLTA SIngkarak	2002
15	Project Completion Report on the Power XX Project (loan no 1031-INO) in Indonesia	Asian Development Bank	1999
16	Project completion report : Singkarak Hydro-electric power project Volume IIA Project Design Data	Colenco Power Engineering LTD in assosiation with PT Citaconas, PT Asianenco and PT Geobecon	2000
17	Proposal penanganan kawasan danau Singkarak secara terpadu	Badan Perencanaan Pembangunan Daerah propinsi Sumatera Barat	2002
18	Potensi danau Singkarak dan ekosistemnya ditinjau dari aspek sosial ekonomi masyarakat	Masrial Akmal	2003
19	Kebijaksanaan pengelolaan danau di Sumatera Barat	Ir. Isrin Agoes – Bapedalda Propinsi Sumbar	2003
20	Perlindungan ekosistem danau Singkarak dalam mewujudkan pemanfaatan potensi danau yang berkelanjutan	Dr. Badrul Mustafa – Litbang PSLH Universitas Andalas Padang	2003
21	Rambu-rambu hukum didalam menjaga kelestarian fungsi ekologis danau	Erdi janur.SH – Bapedalda Propinsi Sumbar	2003
22	Laporan kegiatan pembinaan percepatan pemulihan lingkungan selingkar danau Singkarak	Bapedalda propinsi Sumbar	2003

All documents are available from the ICRAF Indonesia office for reference.

2.2 Roundtable discussion on Hydrological Impacts of Forest, Agroforestry and Upland Cropping

(Padang 26 – 28 Feb February 2004)

Despite at least a century of research on the relationship between land use changes and hydrological processes, there is still a considerable gap in understanding by the various stakeholders. Key actors in watershed management often develop plans based on perceptions, rather than scientific realities. Furthermore, much of farmer's local practices have been neglected and large-scale 'reforestation' is still seen as a 'one-size-fits-all' solution. Little or no appreciation is given to farmers practices in providing environmental services. As such, much of the intervention in watershed management give little impact for the amount of money spent and sometimes coercion occurs between local farmers and formal institutions. With an emerging interest in replacing regulation and top-down project planning by transparent outcome-based reward schemes for actual environmental services provided, there is a need for simple criteria and indicators of the key services. Such criteria and indicators should be based on the best of current science and match the broad objectives identified for local integrated natural resource management policies.

The objective of these activities:

- Establish a set of criteria and indicators of 'watershed functions' that reflects current research results and matches expectations of stakeholders and policy makers in watershed management
- Discuss application of these criteria and indicators to a few watershed management projects in West Sumatera
- Explore how 'rewards for actual enhancement of watershed services' can benefit from these concepts, based on the Singkarak RUPES action research site

The executive summary for the activities :

1. ***Watershed functions and the way they are affected by 'development' are much debated and are nearly everybody's concern***
   When natural forests are logged or cleared by slash-and-burn methods for establishing tree crop plantations or upland food crops, when roads are built on forested slopes and induce landslides and rapid pathways for mud streams to reach the rivers, when people start to live in upper watersheds and pollute streams by domestic use, livestock or use of agrochemicals, when the demand for water increases because of greater use for lowland irrigation, industry or cities, when fast-growing trees that use more water than other vegetation are planted, when government agencies claim control and impose their solutions on the local community, when the floodplains and wetlands that used to provide storage and buffer capacity are drained for 'development' or when villages are built in places that are prone to flooding and mudslides, the end result is 'problems with watershed functions' that affect all of us one way or another.

2. ***There are many ways in which specific problems can be solved through combinations of forests, agroforestry and upland cropping***
   The standard solution to 'rehabilitation of watersheds' is to plant trees in the hope of re-creating the benign conditions of a natural forest. Natural forests, however, provide livelihood options only at low population densities, so it cannot really solve current pressures on the land in areas with high population densities. Tree planting as such may actually increase the problem (fast-growing trees with high water use will reduce dry-season flows of streams and rivers), while mixed multi-strata systems can protect the soil and maintain water quantity and quality as well as providing livelihood to resource-poor local community.

3. ***When once we have a common perception (criteria and indicators) of what exactly is the problem to be addressed***

Because there are many potential 'solutions' we need to be clear and specific about what the problem is and whether the selected solutions really address the problems. A list of three criteria for ***water quantity*** (Transmit water, Buffer peak flows, Release water gradually), ***water quality*** (Reduce sediment loads and other pollutants, Maintain aquatic biodiversity) and integrity of the land surface (Control landslides, Reduce loss of fertile topsoil through erosion), needs to be combined with criteria that relate to biodiversity conservation and to the social and economic welfare of the people living in watershed areas. Once seen against these criteria, many 'solutions' are in fact causing new problems. The different stakeholder may in fact have opposite interests, and a broad process of negotiation is needed to establish integrated natural resource management.

4. ***For example the way the GNRHL tries to achieve environmental protection goal may miss opportunities to build on local participations***
   Indonesia's current national program for reforestation and land rehabilitation is aimed at addressing widespread concern over degradation of watersheds, through a program targeted at planting X million trees per year on 500,000 ha of 'critical lands'. Assumptions that are yet to be met for the program's success are:
   - Convergence in stakeholders' perception on underlying knowledge of what the trees can actually provide to the environment and the community
   - Suitability and synergy of the supplied tree seedlings with existing local agro-ecosystems
   - Guarantee for acceptance by the local community and maintenance after planting to ensure tree survival
   - Guarantee for non-disruption of local livelihood because of changes in land use systems
   - Community education since early stage, starting from primary schools, on science based, rather than myths, of the relationship between land uses and the environments as well as socio-economic conditions
   - Institutional strengthening at the local/farmers level
   - Application of participatory approach (as opposed to a 'project' approach) with 'pendampingan' ('facilitation') of NGOs and researchers, including empowerment of local community in accessing and utilizing local land and tree resources.

5. T***o support the various ways in which proper land management with trees can provide local as well as national (environmental) benefits,***
   Indonesia is rich in examples of landscapes where farmers have combined the use of trees for productive purposes with elements of the natural forest that provide environmental services and areas that are used for intensive food crop production. These 'agroforestry mosaic' landscapes can be seen as 'Kebun Lindung' ('protective gardens') that offer great opportunity for combining economic and environment targets. Yet, there are obstacles in the recognition of these systems, as they may not meet the legal definitions of 'forest' or be in conflict with the existing land use regulation system and policies – even though it could pass the test when ***functional*** criteria and indicators of forest would be used.

6. ***While ensuring that outside stakeholders provide recognition and rewards in ways that are transparent, effective and pro-poor.***
   New ways to build 'hulu-hilir' (upstream-downstream) relationships that can satisfy everybody's needs, will require ways to share the benefits that lowland community enjoy from the effectively protected water resources, ways to enhance recognition and respect for upstream communities and their ability to monitor and solve problems, and means to reduce rural poverty. A combination of ***public*** and ***private*** rewards and payments is most likely to be successful in watershed management. Test sites for this new approach include the Singkarak and Sumberjaya (West Lampung District) action research sites of the RUPES (Rewarding the Upland Poor for Environmental Services They Provide) program.

Our overall message is:

We need to rebuild effective communication between local, scientific and public/policy perceptions and knowledge of the problems that development can cause to 'watershed functions' and try to find solutions that build on local opportunities rather than blue-print standardized solutions.

2.3 Spatial analysis

2.3.1 Location of the study site and baseline spatial data

Singkarak Basin is located at the middle part of West Sumatera Province, Indonesian and covers an area of approximately 1135 km2. The basin belongs to two districts (*kabupaten*) Kabupaten Tanah Datar in the northern half and Kabupaten Solok in the southern half. Geographical boundary of Singkarak Basin is 100.39d-100.75d Longitude and 0.3d-1.04d Southern Latitude. Appendix 2 shows administrative boundaries around Singkarak Basin and its vicinity.

Several maps are important as baseline information of the study site. The relevant maps having been collected for this study are presented in Appendix 1.

Maps available as secondary data sources are often available only in analog format. For this particular situation **digitization** is opted. Particularly for RHA, maps digitized from hardcopies were:

- Administrative boundaries, i.e. Kabupaten boundaries and Nagari boundaries.
- Geology (scale 1:250,000)
- Land Unit and Soil (1:250,000)

The map of Nagari boundaries can be seen in Appendix 3.

Two types of parameter groups, namely Land Cover/Use and Land Form & River Network are necessary for model input in GenRiver. These parameter groups were produced using various approaches and methods in Remote Sensing and GIS, and will be explained separately in chapters 2 and 4.

2.3.2 Geospatial Data Properties

Spatial data exist in various formats and geographic parameters. For the purpose of overlay, the same geographic parameters should be ensured. The information to pay attention to are:

a. Projection
b. Coordinate system
c. Ellipsoid and/or Datum

a. Projection

Map projections are attempts to portray the surface of the earth or a portion of the earth **on a flat surface**. Some distortions of conformality, distance, direction, scale, and area always result from this process. Some projections minimize distortions in some of these properties at the expense of maximizing errors in others. Some projections are attempts to only moderately distort all of these properties (Dana, 2000).

b. Coordinate system

Coordinate systems are used for labeling positions on earth on the map. There are many different coordinate systems, based on a variety of geodetic datums, units, projections, and reference systems in use today (Dana, 1999). Two most common coordinate systems, and commonly used in mapping in Indonesia, are:

- latitudes and longitudes (degree)
- UTM projected coordinate systems (metric)

c. Ellipsoid & Geodetic Datum

Two geodetic parameters (Ellipsoid and Datum) determine the coordinates in the two projection system used. Ellipsoidal models define an ellipsoid with an equatorial radius and a polar radius. Geodetic datums define the reference systems that describe the size and shape of the earth (Dana, 2003). In simpler term, these two parameters represent the earth surface in a particular area and are used as parameters in projection and geopositioning.

Spatial data obtained from various organizations for this study are in different projections and ellipsoids/datums. Following the globally used ellipsoid/datum and also as the standard for all data residing at ICRAF Indonesia, all the geospatial data for this study are in **WGS84 datum** and **latitude-longitude coordinates systems.**

2.3.3 Digital Elevation Models (DEM) and derived attributes

2.3.3.1 Digital Elevation Model (DEM) based on radar data (SRTM)

A Digital Elevation Model (DEM) is needed in the studies on hydrology and hydrological modeling for its derived information on topographic and hydrologic attributes and the secondary attributes derived from them.

DEMs are commonly in the form of raster format, with the pixel values denoting the elevation. Sources for (re) producing DEM are quite varied, and one of which is the output from radar-based topographic mapping done globally by JPL (Jet Propulsion Laboratory) and NASA (National Aeronautics and Space Administration), called SRTM (Shuttle Radar Topography Mission). These near-globally-produced DEMs are processed from C-band radar mapping (for detailed information visit: http://www2.jpl.nasa.gov/srtm/). SRTM data are organized in rasterized tiles, and for the coverage outside USA each tile covers one degree by one degree in latitude and longitude. The cell size in each tile equals to 3 arc-seconds, thus the name of this data set being SRTM-3. The cell size of SRTM-3 equals to 90 m, since 1 arc second in equator corresponds to roughly 30 m in horizontal extent.

SRTM-3 data set is available for free and is downloadable from http://edcsgs9.cr.usgs.gov/pub//data/srtm/Eurasia/. NASA claims that the current SRTM data are preliminary products distributed for evaluation by the research and applications use community. It still contains artifacts and is not intended for navigation or other critical, operations-related applications. (National Aeronautics and Space Administration, 2003)

2.3.4 Acquisition and processing

To comply with the DEM need for the whole Singkarak Basin and the downstream area, a set of SRTM-3 data was downloaded covering the central part of Sumatera from the east coast to the west coast, with the tile IDs shown in Figure 2.1

.

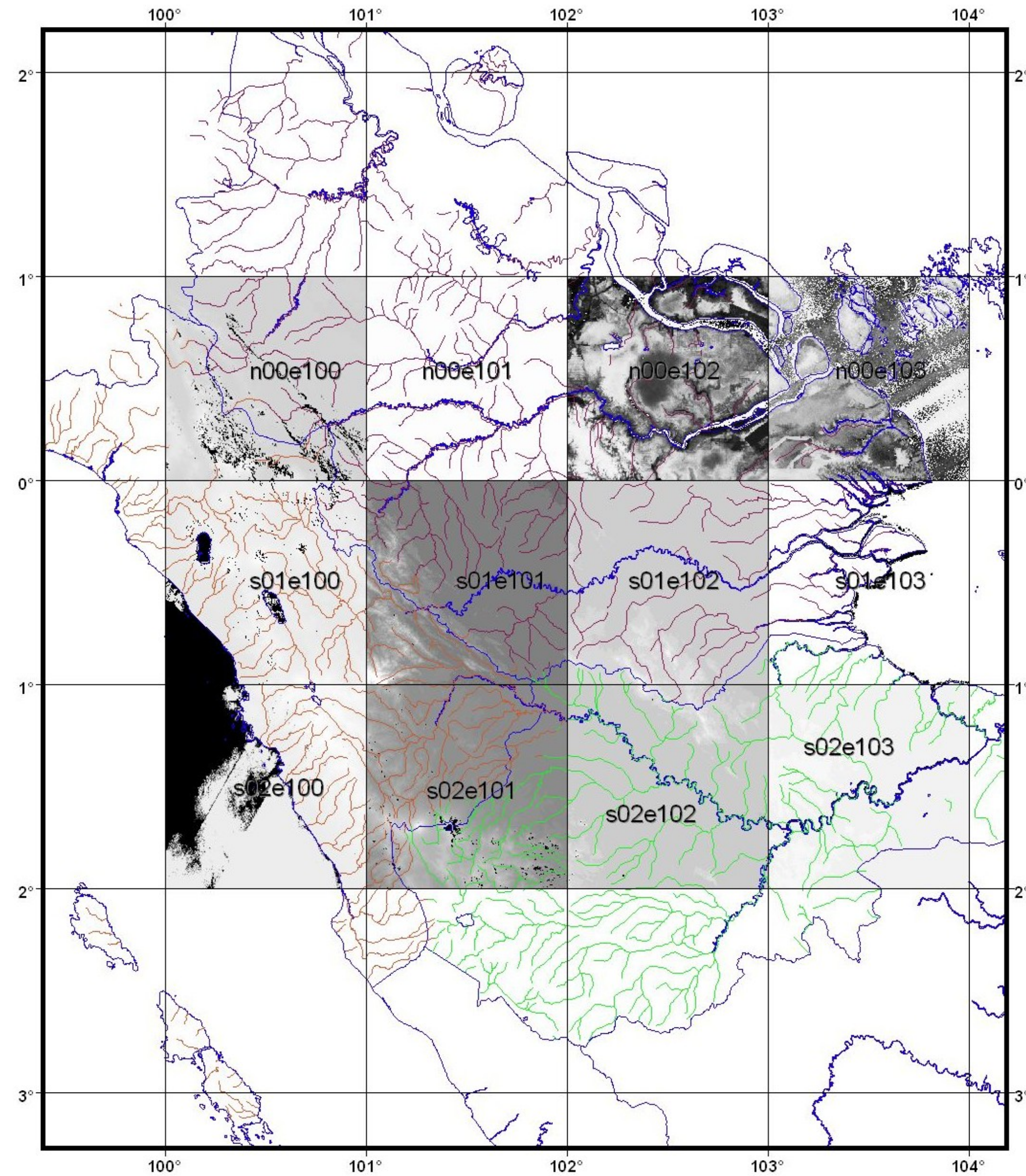


Figure 2.1 Tiles of SRTM-3 covering central part of Sumatera

The individual tile still contains artifacts, missing values and erroneous values for the non-land area (sea), therefore editing processes were conducted to the individual tiles to remove the artifacts and fix the missing values. The editing included "cleaning" the areas where artifacts exist and "interpolate" the neighboring values to "fill" the missing values. See Figure 2.2 as an example.

After being fixed individually, all sheets were mosaicked into one sheet. The next level of correction is to remove elevation information for the non-land (sea) part, and adjust the elevation of the lakes by using height of the water level.

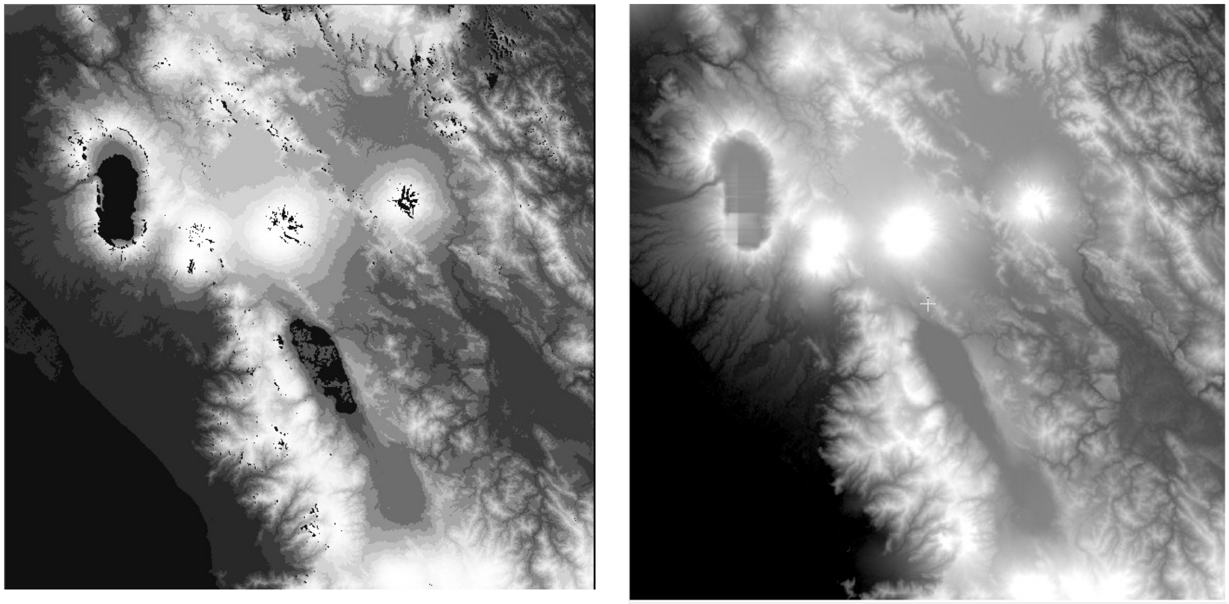


Figure 2.2 (a) Original SRTM-3; (b) Edited SRTM-3

2.3.5 The DEM as basis for further analysis

The final DEM can be seen in Figure 2.3.

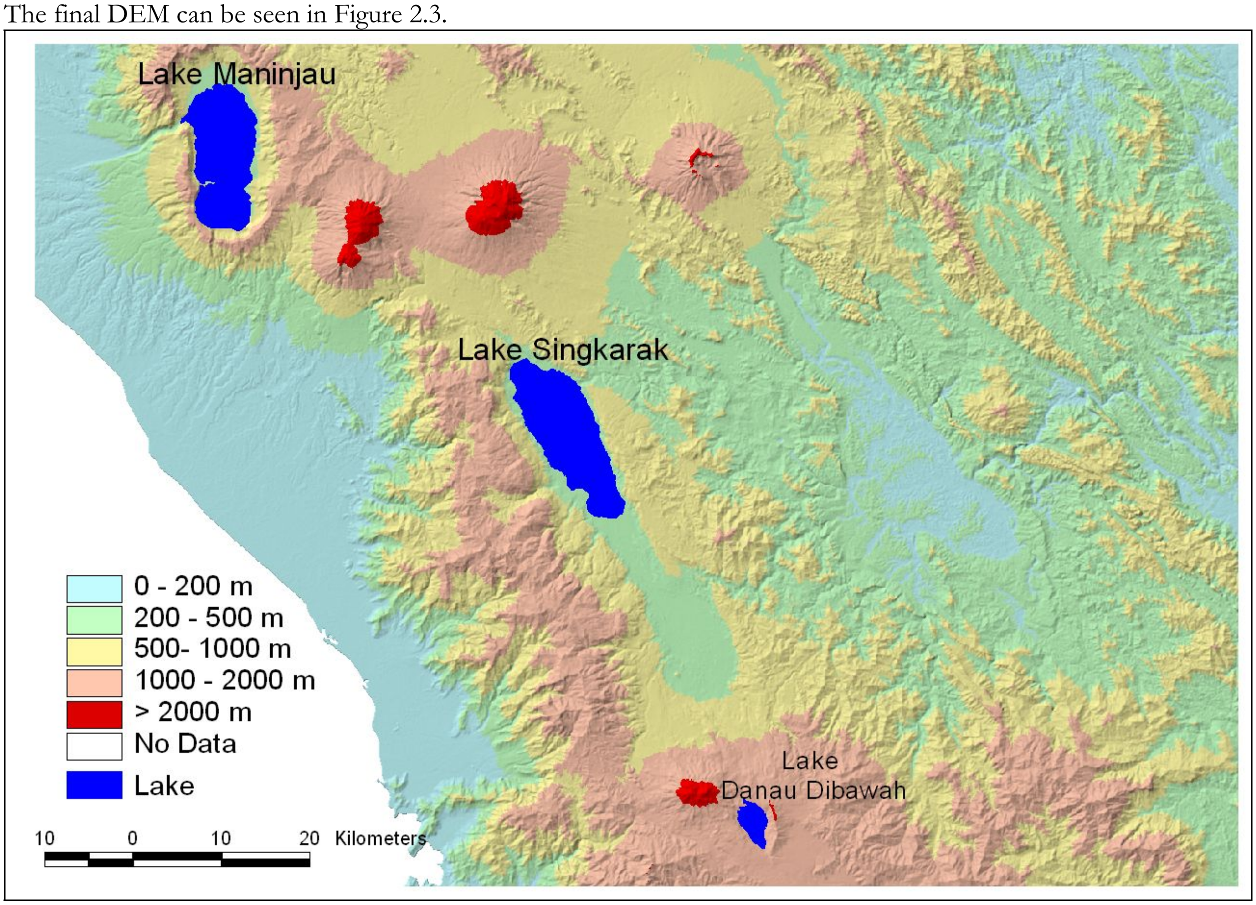


Figure 2.3 Digital Elevation Model of Singkarak Basin and the vicinity, produced from SRTM-3

The objectives of DEM-derived attributes extraction are to obtain:

a. Slopes –landform description
b. Drainage features (streams)
c. Subcatchments as the units of analyses
d. Routing distance:
    - of the streams from each subcatchment to the lake
    - of the streams from each subcatchment to an observation outlet (i.e. outlet of aggregated subcatchments)

Especially for subcatchment and routing distance extraction, they are parts of model inputs for GenRiver model, by which the quantification of hydrological assessment in Singkarak Basin will be done. Routing distance to the lake is to obtain the time lag of stream flow from each subcatchment to the lake. Routing distance to an observation outlet is for the purpose of parameterization with the field data possible to be obtained at an observation point (of the aggregated subcatchments) .

To obtain those topographic and hydrologic attributes the processed SRTM DEM was used.

a. Slope

Slope is defined as the increase in vertical direction (dz) per distance in horizontal direction (dx). The calculation of slope takes the eight neighboring cells or 3x3 cell window. The method follows 'third-order finite difference' by Horn (1981) (PCRaster Environmental Software).

b. *Hydrological attributes*

In principle, the hydrological attributes extraction follows the method by Jenson and Domingue, 1988, implemented in Hydro module of ArcView (Environmental Systems Research Institute, Inc., 1999) and can be seen in Figure 2.4.

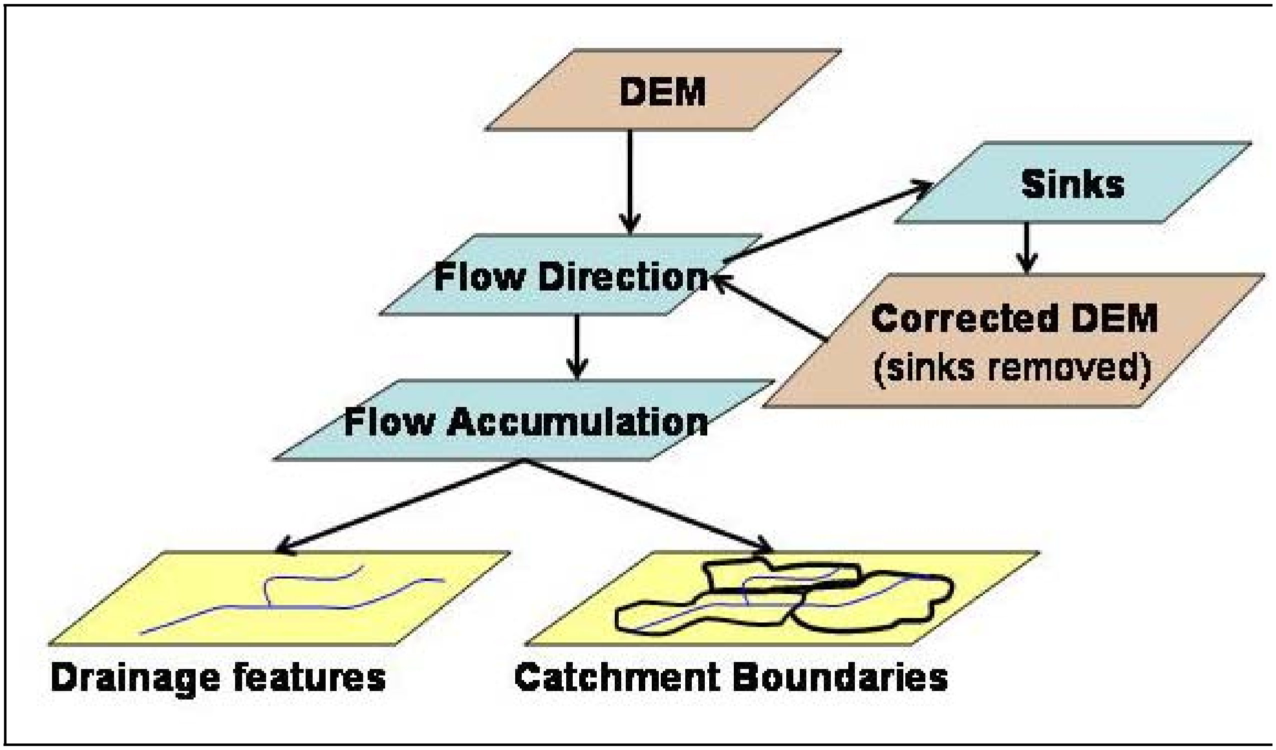


Figure 2.4 General work flow of hydrological features extraction in ArcView Hydro Module

Where:

Flow Direction	: each cell is assigned a value denoting the direction of the flow based on the height differences of its neighboring pixels
Sink	: cells identified as having no outlet, being the lowest in height compared to its neighboring cells
Flow Accumulation	: each cell is assigned a value of accumulated number of cells contributing their flow to that cell

Based on those basic parameters, the following hydrological attributes were extracted:

Drainage features
By defining threshold values for the flow accumulation grids, drainage features (streams) can be defined. Using the example shown in Figure 2.5, by calculating the flow direction grid cells (a), flow accumulation grid is created (b). Assuming that streams occur with 2 cells or more of flow accumulation, stream is defined (c).

After several trials, threshold value of flow accumulation cells of 500 cells, which means 500*8100 m2 = 405 Ha, was defined as streams. Since the stream is elevation-derived, errors do occur, especially for the occurrences of lower order streams (tributaries from the upstream area). Therefore, field verification is needed for the true occurrence of streams.

In flat areas, where elevation differences among cells are not significant, occurrence and shape of streams will be likely erroneous, i.e. the river tends to be straight, while in reality very likely meanders and curves occur in the rivers in flat areas (downstream).

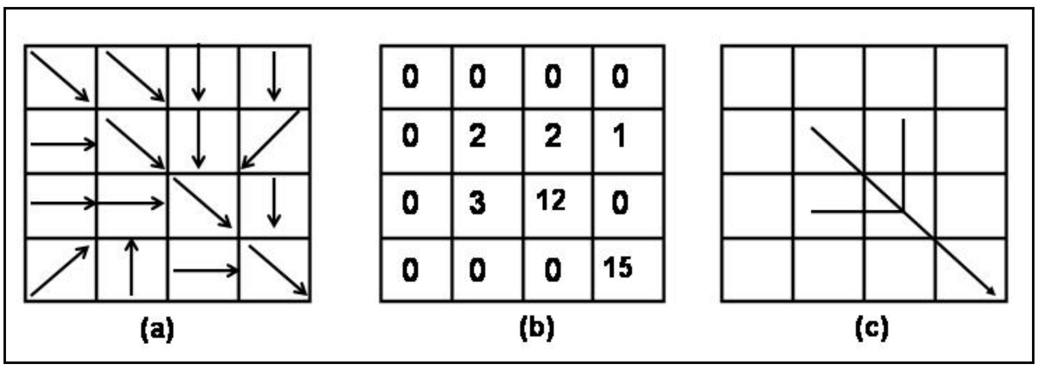


Figure 2.5 Examples (a) Flow direction grid; (b) flow accumulation grid; (c) stream grid

Basin and subcatchment boundaries
Catchment boundaries are generated by tracing the flow direction from the defined outlet back to the beginning cells.

For subcatchment boundaries, threshold values are used to define micro catchments in the basin, and then the final sub catchment boundaries were produced from aggregating several small subcatchments. To make sure they are hydrologically correct, streams are taken into account and single outlet is ensured for each subcatchment. Exceptions take place for the subcatchments around Singkarak Lake, because in this part the subcatchments are small and narrow and directly flow to the lake. The subcatchments resulted from aggregation have several outlets for each.

As also with the stream delineation, (sub) catchment boundary delineation is also problematic in flat areas. Therefore, verification is needed for further uses and analyses in the field or with finer scale spatial data.

Routing distance extraction (-- for Water Balance Model of GenRiver)

Two routing distance types were calculated for this particular work.

- Routing distance to the lake
- Routing distance to an observation outlet (i.e. outlet of aggregated subcatchments)

To determine the starting point of routing in each subcatchment, centroid of the subcatchment was used. Afterwards, the routing distance was calculated by measuring the stream length from the stream segment closest to subcatchment centroid to targeted outlet.

2.3.5 Methods for land cover classification

2.3.5.1 Image Acquisition

Land cover information for RHA with GenRiver model is principally for the purpose of obtaining vegetation-based parameter groups influencing hydrological cycle. Two parameters to be derived from Land cover are **infiltration** and **evapotranspiration**

Land cover information was derived from geometrically corrected Landsat ETM images. The term 'land cover' in this study refers to the observed (bio) physical cover on the earth's surface*; it* could also be confined to describe vegetation and man-made features.

Remote sensing data of Landsat Enhanced Thematic Mapper images were used in this study to produce land cover map of Singkarak Basin. Table 2.1. describes the specifications of the Landsat images. Images were acquired from *Tropical Rain Forest Information Centre (TRFIC) (http://brsi.msu.edu/trfic)*. High level of cloud covers in the area made it difficult to have two adjacent images from the same year of acquisition. Therefore the images that were used had one-year difference, with the details shown in Table 2.1.

Table 2.1 Image specifications of Landsat Enhanced Thematic Mapper

Specifications	**Landsat P127 R060**	**Landsat P127 R060**
Acquisition date	May, 18th 2002	May, 5th 2001
Number of channels	8	8
Sun azimuth	53.77	48.93
Sun elevation	55.62	53.19
Cloud cover	20%	15%

Note: P=path R=row

2.3.5.2 Classification procedures

In general, the methods is presented in flow chart in Figure 2.6

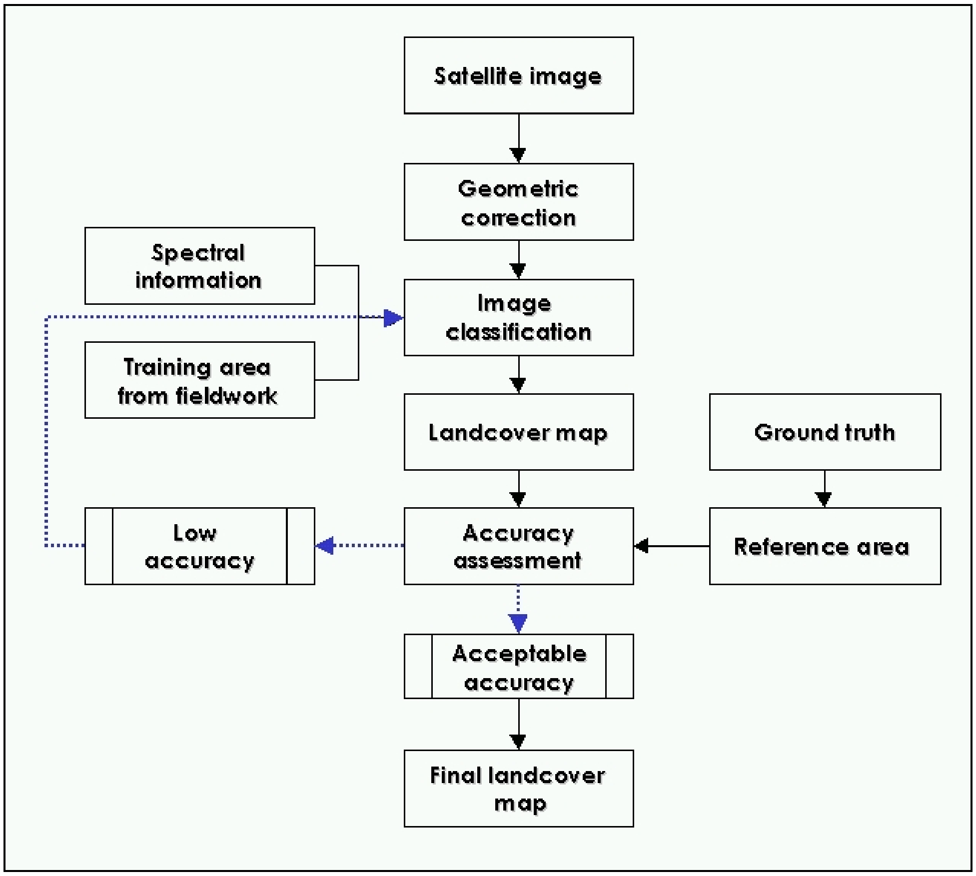


Figure 2.6 Flowchart of Land cover mapping study

Geometric correction was carried out by rectifying satellite images through a set of ground control points (GCP), to an earth coordinate system. *Image to map rectification* methods were used in this process. Ground control points were extracted from 1:250,000 topographic map produced by *Badan Koordinasi Survey dan Pemetaan Nasional (BAKOSURTANAL)*. Geographic coordinate system (latitude-longitude) with *Indonesia'74* datum was used in the rectification process, following the coordinate system of the topographic map. At the later stage, the datum was converted into WGS 84 to comply with the standardized datum.

Ground control points (GCP) were placed on easily recognized objects such as road intersections, bridges, and, for some locations, river branches. Since the topographic map is only available in hardcopy format, the geographic positions of those locations were extracted from topographic map by means of manual measurement, i.e. using ruler. The manual measurement was considered to have a 0.5 mm error. The precision of the resulted measurement will indicate minimum possible error to be expected after image geometric correction process. In this case, 0.5 mm precision on a 1:250,000 topographic map means 125 m or approximately 4 pixels of 30m resolution-Landsat ETM image.

Table 2.2. shows the total number of ground control points used in the geometric correction process, the average of root mean square error (RMSE) and the maximum/minimum residual error from all GCPs. Average RMSE shows that the probability of overall distortion of the corrected images is approximately **140 m** in any direction**.** This RMS error is as well used as the planimetric accuracy of the satellite image and its derived products relative to the

topographic map, which is crucial to take into account for any further data extraction and application

Table 2.2. Result of Geometric correction

o	Factors	Landsat 126/061	Landsat 127/061
1	Number of GCP	57	30
2	RMSE on x-axis (m)	100	100
3	RMSE on y-axis (m)	102	96
4	Average RMSE (m)	144	138

The final step of image preprocessing is *image mosaicking*. This process aims to combine the two-geocorrected images to produce a seamless mosaic of Landsat images covering the part of Singkarak Basin. Geometric correction and image mosaicking were all conducted using *Orthoengine* module in *PCI Geomatica*. Figure 2.7 shows the geocorrected Landsat ETM images covering Singkarak Basin and vicinity.

Field Observation of Land Cover Types

An initial field observation conducted in early April 2004 provided very useful information about existing land cover types in Singkarak Basin, West Sumatera. This information was used to define types and characteristics of land cover in the area. There are 8 major land cover types, to be used in image classification process.

a. *Forest*

Forest cover is defined as an area characterized by more or less dense and extensive natural tree cover usually consisting of stands varying in characteristics such as species composition, diameter distribution, total basal area age class, which may be exploited (partly logged). This class will include both primary and secondary forest in Singkarak Basin.

b. *Pine*

The physical appearance of pine area will be closely similar to that of industrial monoculture forest plantation. Pine class represents an area which is totally or mostly covered by pine trees (*Pinus sp.)* at a mature to old age. The density of pine in this class cannot be defined since there are no supporting data. Pine exists on several areas which are undergoing or have undergone reforestation phase. It is located mostly on the highland and a post-cleared hill slope.

c. *Mixed garden*

Mixed garden refers to a smallholder fruit-based agroforestry system, privately managed by local people. This class is covered by a mixture of fruit trees such as durian (*Durio sp.),* avocado, lime, jackfruit , as well as other trees, like cloves, nutmeg, candle nuts. In some areas it is intensively managed, shown by weeding activities noticed in the field, while many others are left unmanaged. The unmanaged-mixed gardens consist of a combination of fruit trees, woody shrubs, and non-fruit trees. Another type of mixed-garden around Singkarak Basin is a coconut-based agroforestry system, with coconut as the dominant species.

d. *Agricultural field*

Agricultural field refers to a patch of land planted by horticultural crops, i.e. vegetables. This type of land cover is intensively managed.

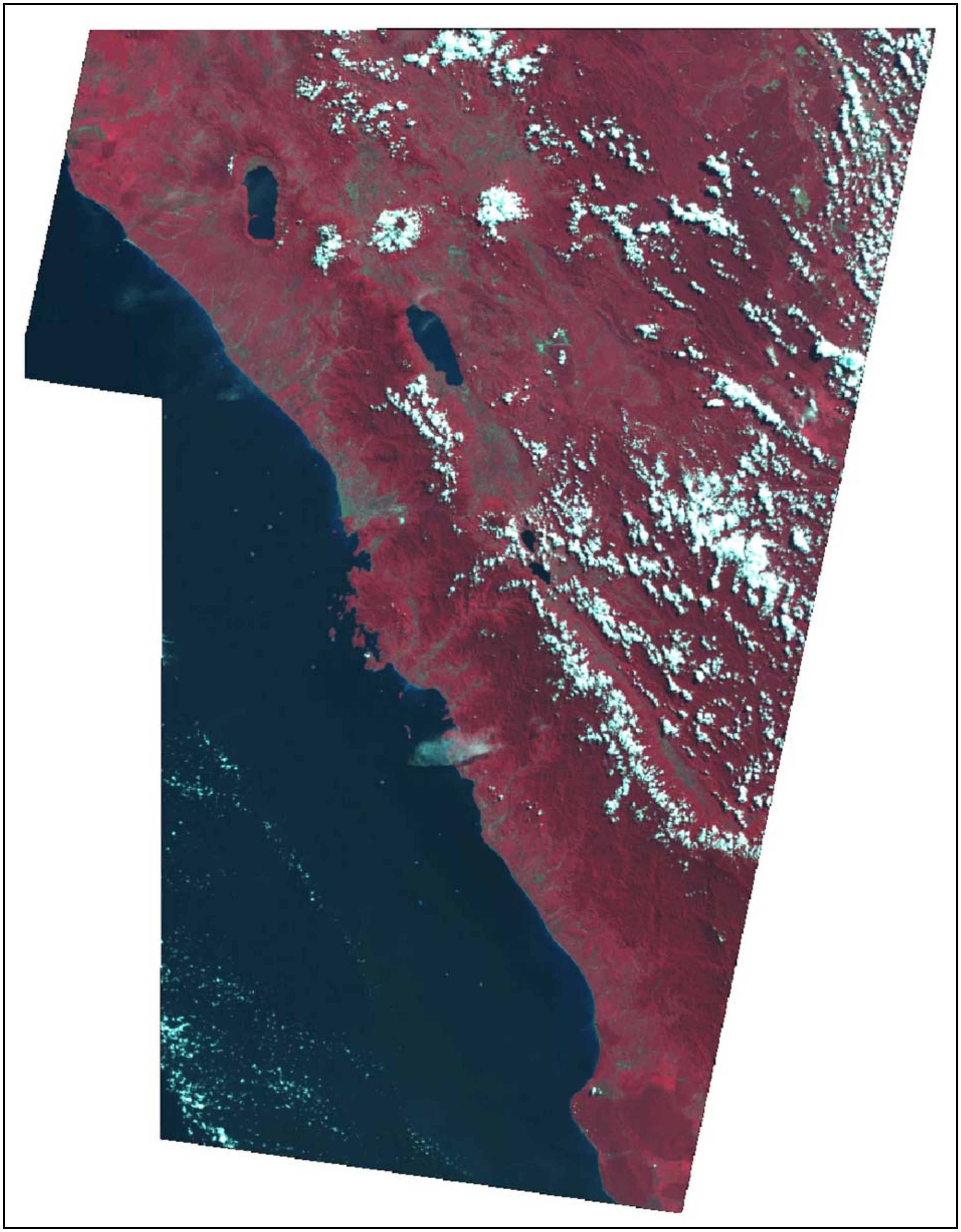


Figure 2.7 Mosaicked-geocorrected Landsat ETM image

Figure 2.8 Pine forest in the hills of Paninggahan

Figure 2.9. High density fruit-based mixed garden

Figure 2.10. Vegetable crops

e. *Rice field*

Ricefield is defined as a patch of land planted by rice, including the inundated rice field. Both irrigated and upland rice are considered in this class. Ricefields usually exist close to settlement and mixed with agriculture fields in the landscape.

f. *Shrub*

Shrubs are characterized by an area covered by mostly woody-herbs combined with grass. These areas usually correspond to recently opened/-abandoned area, caused by shifting cultivation activity. Other forms of shrub in this class are abandoned land where farmer have left their land unmanaged for various reasons or lands left after fire/forest clearing. Shrub may represent degraded /critical land.

Figure 2.11. High-density shrub and degraded lands in Paninggahan, West Sumatera

g. *Grass*

In some areas, the physical appearance of grass is almost similar to shrub. The major difference is that most of the vegetation cover is usually non-woody herbs and *Imperata*.

h. *Settlement/Built-up area*

Settlement represents an area used as human residential area, including main road and village.

Object- based Classification

Object-based classification is a new approach in digital image classification techniques, which uses *image objects,* instead of single pixels, as the main units of observation in classification process. Image object refers to a set of *homogenous* pixels, which are assumed to represent actual objects on earth. These homogenous pixels are identified through image segmentation process by considering factors of shape, scale, and color (spectral similarity). In general there are two steps followed in this method*: segmentation* and *hierarchical land cover classification*

a. *Segmentation*

Segmentation was carried out several times to produce image objects with different scale parameter, which represent different size of objects in the earth surface. For example, one will need a fine scale of image segments to be able to classify road and river, but the scale won't be necessary needed to classify larger objects such as forest patches or agricultural fields. To this extent, segmentation was mostly guided by visual inspection, or if it exists, assisted by very high resolution data. The result of segmentation process is a structure called multiresolution image objects, while the term resolution refers to a "levels of details" to accommodate different sizes of image objects.

b. *Hierarchical land cover classification*

To label the objects into land cover classes, a hierarchical structure was used. In each level, different types of spectral and spatial information, object size, and characteristic of land cover types, are utilized. The hierarchies assist in organizing large amount of information from a satellite image. Figure 2.12 shows the hierarchical classification structure.

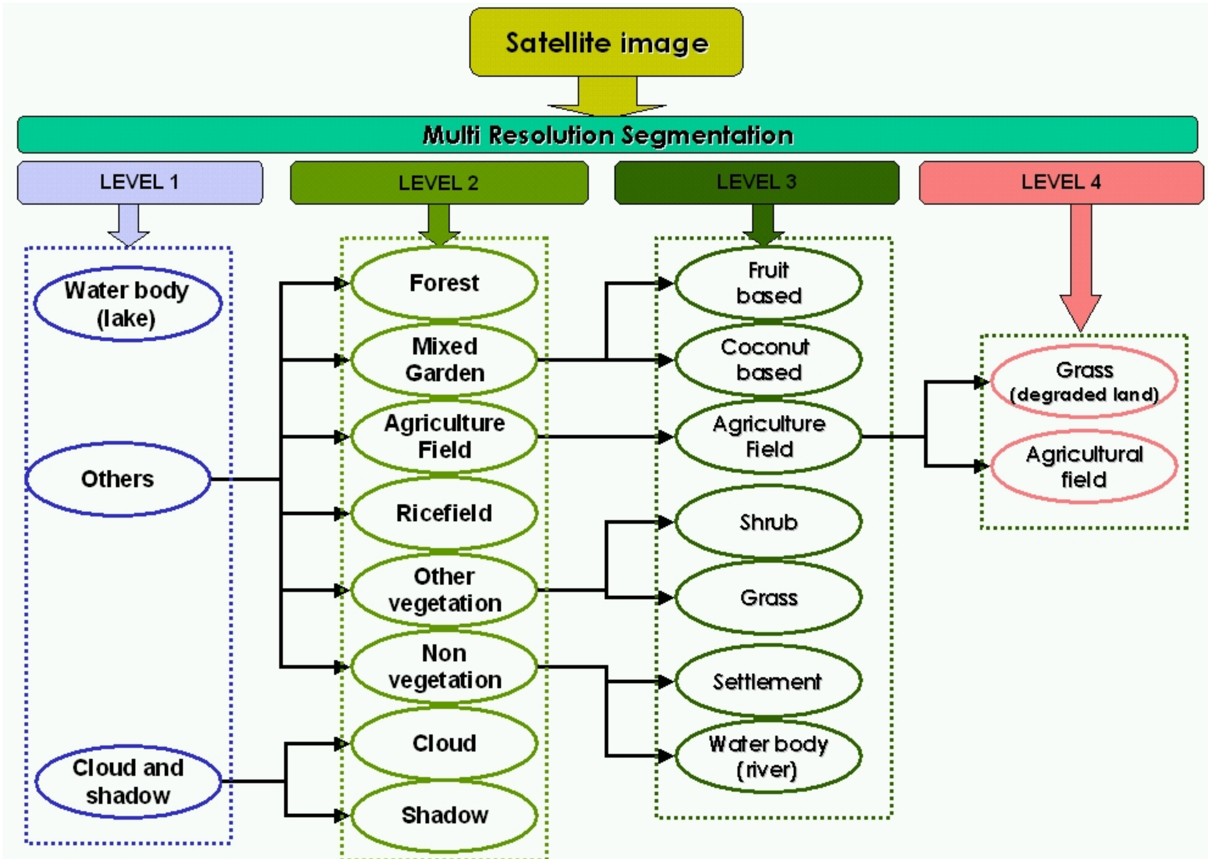


Figure 2.12 Flowchart of hierarchical classification

Land Cover information extraction

The resulted classified image was exported into vector format and combined with other spatial information to be able to extract the information required by the GenRiver model, i.e. and cover proportions in Singkarak Basin, in each *Nagari*, and in each subcatchment. GIS operation of intersection between the area and the land cover map was conducted to achieve proportion of each land cover in each unit of interest.

Segmentation

After some trials guided by visual inspections of the original image, segmentation was carried out in 3 levels. Figure 2.13 shows a subset of segmentation results of different levels; original image (upper left), level 1 segmentation (upper right), level 2 segmentation (lower left) and level 3 segmentation (lower right).

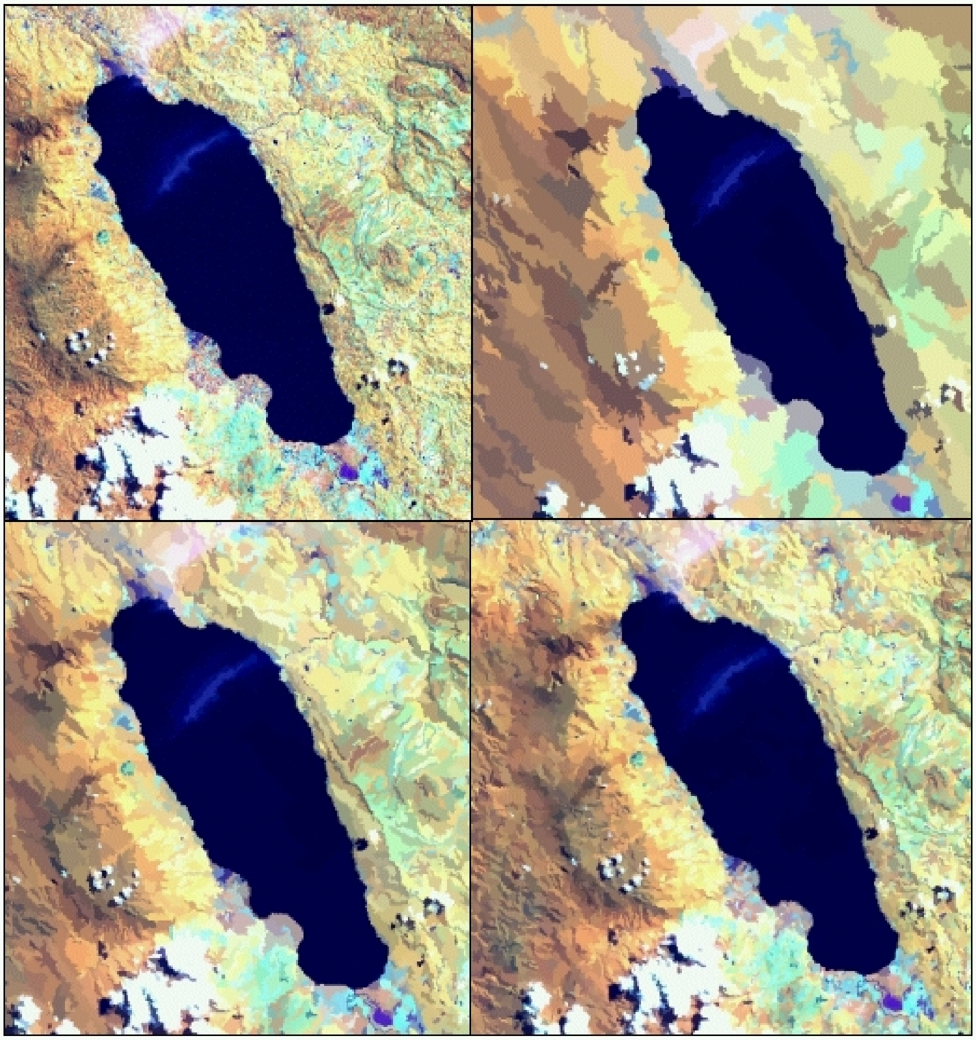


Figure 2.13. Segmentation results from different levels.

2.4 Local Ecological Knowledge (LEK)

The local ecological knowledge methodology (Dixon et al, 2001) already in use under various research activities at ICRAF was adapted for the purpose. However, the detailed and rigorous iterations of individual interviews were replaced by detailed discussion with small homogenous groups of people. Moreover, the software Agroecological Knowledge Toolkit (AKT) was inappropriate due to a need for a rapid approach of exploring and assessing knowledge and experience.

Overall, the following stages were planned prior to going to the field:

Stages	Methods	Expected output	Time
Stage 1: Scoping - Preliminary orientation and rapid characterizing of the domain and issues of concern	Observation, expert consultation, sketch mapping	Sketch map, domain description, stakeholder group selection	3 days
Stage 2: Planning for group interviews - Choosing sites representing identified issues; checklist preparation and pre-testing	Site visits and discussion	Sites or "cases" selected for group interviews; checklist finalised	2 days
Stage 3: Knowledge articulation	Group interview and discussion during transect walk(one group a day)	Knowledge and perception of hydrology issues from each group on all reference sites or "cases"	5 days
Stage 4: Data compilation and preliminary evaluation	Summarise interview data (playback recordings) and reconfirm where necessary; field report preparation	Report of knowledge and perception of different stakeholder groups	4 days

Stage 1: Scoping

A. This stage included initial field visits, consultation with local and external experts to understand the domain, the hydrological issues of concern and to identify the major stakeholder groups**.** A sketch map of the village/catchment area was prepared with major land use systems and other necessary details. Areas with issues of concern (e.g. flooding, landslides, drought) are marked in the map (Figure 2.14).

B. Stakeholder groups for interview and discussion were selected. These consisted of male farmers, female farmers, government officials and non-government officials in Paninggahan.

Stage 2: Planning group interviews

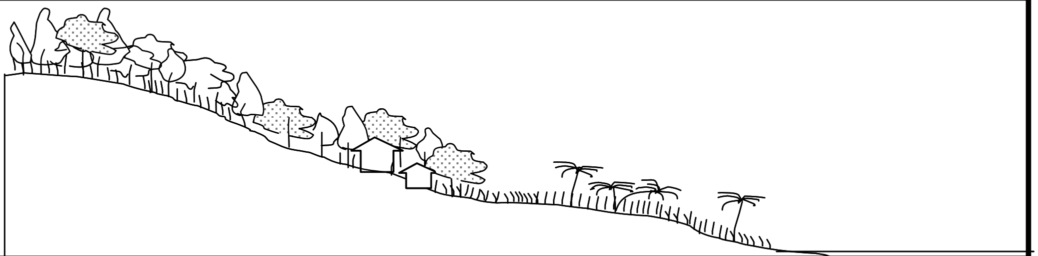
A. Along the transect route sites representing issues of concern (e.g. erosion, flood, land use, sedimentation, water contamination) were identified and these sites were used as "reference cases" for group interviews and discussion.

B. Checklists for interviewing different groups were prepared

Stage 3: Knowledge articulation

A. Transect walks with stakeholder groups (start from top). General local issues and issues of concern were discussed at the highest point with a clear view of the whole catchment. At each reference site thereafter, further discussions about the stakeholder group's knowledge, perceptions and views were conducted. The checklists were used and the whole discussions/interviews were recorded on a tape (to avoid taking notes and other distractions). The total transect will be completed between 1 to 2 hours.

B. The tape recordings were later played back to prepare notes and appropriate cause-effect diagrams.



LAND USE	Pine forest, Natural forest.	Home garden	Rice field, arable land	Lake
WATER SOURCE	Spring	Spring, river,	Spring, River, Bank of the lake.	
TREE	Pine, Clove, Coffee, Teak, Mahoney, Sawo, Avocado, Melinjo.	Avocado, Clove, Sawo, Kemiri, Banana, Fruit tree.	Rice, Coconut, Kapok.	
CROP			Rice, mayze, Chili, Onion, Soybean	
SLOPE	Steep	Sloping	Flat.	
LAND TENURE	State land (Tanah Nagari), Community land (Tanah Ulayat), Private land (Tanah kaum)	Private land (Tanah kaum)	Private land (Tanah kaum)	
FAUNA	Harimau, Kelelawar	Dogs, monkey	Tikut, Ikan	5 type of fish: Ikan bilih, Ikan Sasau, Ikan Balingka, Ikan Gariang, IKan Asang.

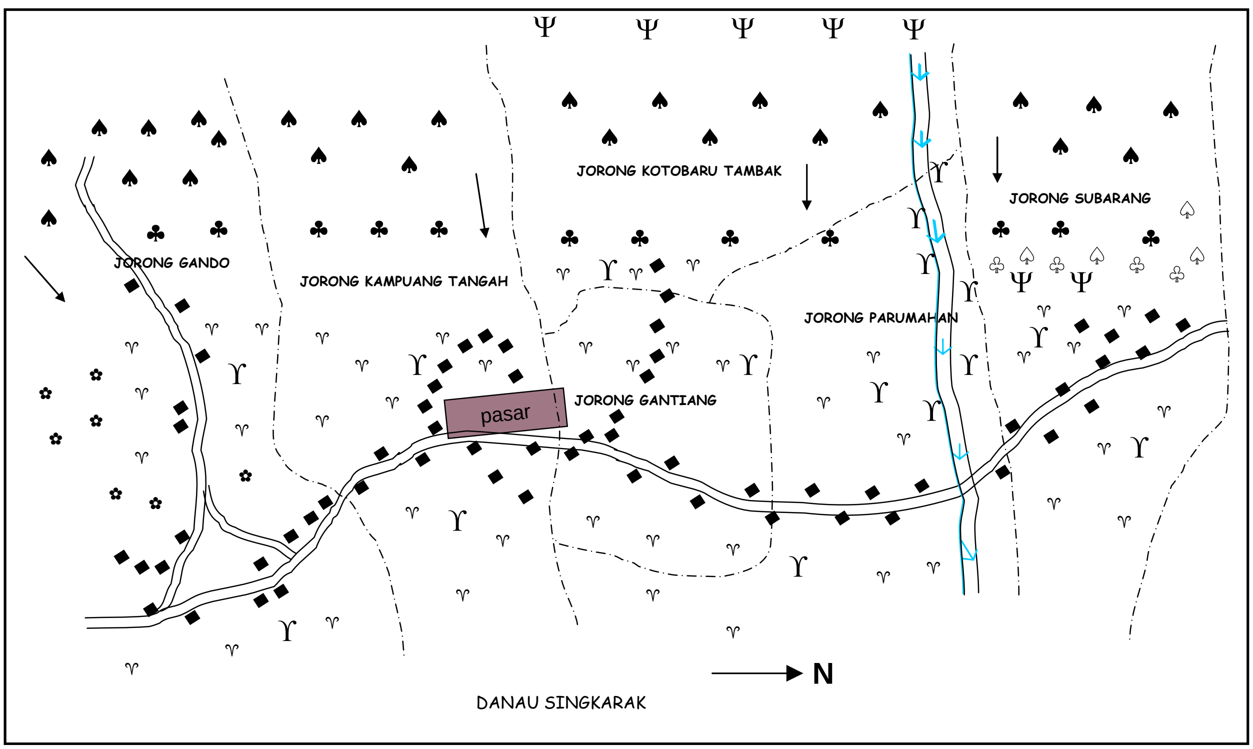


Figure 2.14 Sketch map as developed during the participatory landscape analysis

Stage 4: Data compilation and preliminary analysis

A. Data from all stakeholder interviews and discussions were written up by topic with preliminary attempt to compare between different stakeholder groups. Cause-effect diagrams and other information were prepared. More detailed analysis was planned upon return to Bogor.

2.5 Policy Ecological Knowledge (PEK)

The objectives of the PEK study as part of the RHA for Singkarak were:

1. Development of a 'rapid' method for exploring major issues, problems and associated knowledge and perceptions related to hydrology, water resource and environmental issues among major stakeholder groups.
2. Testing of this rapid approach at macro-scale (outside of the focus RUPES sub-catchment site), across the region within, adjacent and downstream of the Singkarak lake basin in West Sumatera.
3. Testing of the approach as a rapid regional scoping tool, in attempt to define local knowledge and perceptions regarding the significance of environmental impact of (upper) catchment usage, as compared other water resource impacting developments within the lake basin.

The LEK approach, in this case, was further adapted for the purpose of conducting a macro-level basin-wide survey to become the 'public and policy maker's ecological knowledge' (PEK) approach.

With regard to methodology, a 'traditional' LEK approach would employ detailed and rigorous iterations of individual interviews, supported by the data-processing software package the Agroecological Knowledge Toolkit (AKT).

The 'rapid' LEK methodology, employed under this project to focus upon the RUPES Paningghan study site, alternatively adopted the approach of replacing individual interviews with detailed discussion with small homogenous groups of people. Plus has avoided the use of the AKT. These steps taken with aim to reduce the logistical effort (time and expense) of the field data collection and analysis stages of the survey, in the hope of delivering a 'scoping review' of local perceptions more rapidly and cheaply.

The PEK methodology, has adopted the same 'semi-structured' interview approach of the rapid LEK approach, as the basis for the detailed discussions. However, the list of discussion topics was expanded to support the broader 'scoping review' of land use-related and other possible water resource impacting activities within the lake basin. Plus the list of stakeholder 'groups' interviewed needed expansion to cover the greater number of 'stakeholder groups' within the larger area of the lake basin survey (i.e. all community groups, government levels and agencies with specific interest in water resource, landscape and environmental management.

The expanded number of interview topics, stakeholder groups and physical locations to be covered, combined with limited time access to those to be interviewed[1], has led PEK methodology to focus primarily upon issue identification, location and probable causal factors. In the resulting many brief interviews[2] conducted within the PEK survey, less attention could be

[1] Most interviewees as government officials had limited time available to entertain interview teams, or were just about to leave on, or delayed in coming back from, field trips, meetings, official ceremonies - necessitating very rapid interviews due to limited access time. Alternatively they were unavailable for interview appointments, requiring a return visit, resulting in loss of effective survey time, also reducing time available to be spent for subsequent follow-up interview.

[2] The PEK survey of the Singkarak site was conducted as 44 separate interviews, covering 14 differing stakeholder groups, and a total of 66 persons, over a 17 day period. In comparison

given to exploration of stakeholder's perceptions regarding the 'workings of the processes' than was given within the LEK survey. This is primary difference between the PEK and LEK methodology.

Overall, the following methodological stages were carried out, or planned, prior to going to the field:

Stages	***Methods***	***Expected output***	***Time***
Stage 1: Scoping the Issues – Preliminary orientation and rapid characterizing of issues of concern within the lake basin	*Reconnaissance field trips; introductory workshop with local stakeholders; desk-top review of related reports, maps and development plans (e.g. PLTA scheme reports)*	*Gathering of site maps and reports; conducting workshop; review of water-related environmental issues; & rough definition of impact locations and affected / affecting stakeholder groups*	*5 days*
Stage 2: Defining a Spatial Framework – defining the focus and boundaries of the detailed LEK survey; and limit of extent of surrounding PEK surveys	*Manual definition of related sub-catchment, lake basin, river basin & administrative boundaries from topographic maps.*	*Decision on survey spatial focus for LEK and PEK surveys. Definition of focus sub-catchment boundaries for LEK survey. Definition of lake basin boundary and logical extent of downstream focus for PEK survey.*	*2 days*
Stage 3: Planning for PEK Interviews – discussing the methodology differences from LEK, discussing tentative sites, likely issues and a tentative checklist of stakeholders.	*Discussion with supervising social scientist. Review of differing ICRAF survey methodologies applied under differing projects.*	*Decision on applicable methodology to employ for PEK in view of stakeholder numbers, issues & time available for survey*	*1 day*
Stage 4: Stakeholder and Issue Identification (on-ground) – development of a checklist of key stakeholder groups with local informants & leaders & definition of key issues for discussion.	*Interview with selected provincial and regional agency officials. Reconnaissance tour of lake basin landscape.* *Interview with selected local leaders or agency staff.*	*Development of checklist of target community groups, government officials & agency staff, at provincial & district level, within the lake basin & downstream.* *Development of a checklist of discussion points.*	*5 days*
Stage 5: Knowledge articulation	*Planning location and time schedule for stakeholder interviews. Interview and discussions (groups if possible) during scoping survey of river basin (2 to 7 interviews a day)*	*Development of interview schedule. Knowledge and perception of hydrology issues from each group on all reference sites or "cases"*	*13 days*
Stage 6: Data compilation and preliminary evaluation	*Summarize general output and methodology; summarise interview data (write-up interview notes into database); analyse key issues, problem areas & perceptions as to causal factors; field report preparation*	*Report of public and policy maker's knowledge and perception of different stakeholder groups*	*9 days*

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the LEK survey was conducted as 13 interviews, covering 4 differing stakeholder groups and a total of 23 persons, over a 10 day period.

2.5.1 Stage 1: Scoping

B. This stage was initiated as a desk-top review of available baseline data relevant to the site and its development. Web and literature searches were conducted to identify and collect reports relevant to the lake basin's bio-physical conditions, water resources and environmental issues.

C. The initial stage was followed-up by an introductory workshop in Padang, West Sumatera, and reconnaissance field visit to Singkarak and Maninjau lake areas. These visits involving consultation with local experts, to understand the domain, the hydrological and environmental issues of concern and to identify the major stakeholder groups. This combined with additional report and map collection.

D. Available reports and maps were subsequently reviewed to consolidate the information base concerning environmental and water issues and the possible associated stakeholders. Most specifically the environmental impact reports associated with the Singkarak Hydro-Power Development project.

2.5.2 Stage 2: Spatial Framework

A. The collection and purchase of a suitable series of topographic maps followed to enable more detailed planning of the spatial framework of the LEK, PEK, and environmental scoping surveys, and as a basis to plan the purchase and collection of supporting bio-physical and spatial datasets.

B. A spatial framework definition was subsequently conducted at 1:250,000 and 1:50,000 mapping scales. This involved the mapping of the physical boundaries of the river basin, major sub-basins and related administrative boundaries surrounding and within. As an output our potential scales of study focus were defined:
   - The combined Indragiri and Anai River basins. The broadest spatial setting for a Singkarak lake basin environmental scoping study. Including the Kuantan / Indragiri river basin, the 'natural drainage basin' of Lake Singkarak - draining east from West Sumatera, through Riau Province, to the South China Sea. Plus the Anai River basin, or the 'trans-basin outfall route' of the Lake Singkarak Hydro-Power Scheme discharge, via which the majority of Singkarak's water is now discharged westwards into the Indian Ocean;
   - The Upper Kuantan (Upper Indragiri) River basin, framing the West Sumateran broad environmental setting surrounding the Singkarak Lake Basin (7,527 km^2);
   - The Singkarak Lake basin (1,135 km^2); and
   - The Paninggahan River Sub-Catchment (76 km^2) and Nagari Paninggahan (95 km^2).

C. In view of the hydrological and environmental issues identified under the scoping phase, a decision was required as to what would be the most appropriate level and boundary of study: a) to explore local people's knowledge of catchment and hydrological processes, and landscape and land use impacts, at a semi-detailed level; and b) to explore the public and policy maker's perceptions of catchment, hydrological and environmental processes, and the impact of all combined major projects, development activities and community practices, at a broader river basin level.

D. The resulting decision taken was to focus upon:
   - The Paninggahan River Sub-Catchment (within the Nagari Paninggahan boundaries) as the semi-detailed or 'LEK'-level. This being the only logical and manageable area in terms of: area (7,600 ha) and population level (around 10,000 people); RUPES focus (i.e. Nagari Paninngahan); which could be reasonably surveyed for LEK purposes within a 2 to 3 week period; and
   - The Singkarak Lake basin, and areas downstream within West Sumatera and the broader upper Kuantan river basin, where a hydrological impact of the Singkarak

Hydro-Power Scheme development may still be experienced[3]. This was thought to be the most logical extent of 'PEK'-level 'environmental scoping' survey of the related lake and river basin environmental issues.

2.5.3 Stage 3: Planning for PEK Interviews

A. This stage involved discussion with ICRAF-SEA's social scientists in attempt to define the difference of approach to adopt for the PEK methodology, as compared to the more established LEK methodology (i.e. ICRAF-SEA had not previously implemented a formal PEK survey).

B. Established Participatory Rural Appraisal methodologies were reviewed. Notably the PRA Transect methodology (i.e. joint walk, physical transect, social transect and walk to the demonstration site techniques). ICRAF-SEA's Local Ecological Knowledge (LEK) survey methodology and Participatory Landscape Assessment (PALA) approach were discussed, compared, using differing projects examples.

C. Recommendation was made that group visits with concerned agency officials and local leaders (also considered as policy makers), conducted in form of a transect walk or transect drive, would be ideal. With differing sites selected within the catchment, around the lake, or along downstream river reaches from the lake to illustrate the differing water and environmental issues. Conclusion was reached, however, regarding practicality, that the chance of getting significant numbers of agency officials and local leaders out of their offices and homes and into the field, in such a structured way, was likely to be low.

D. The Rapid Hydrological Assessment (RHA) project proposal was reviewed, taking note of the guideline that LEK and PEK surveys should adopt a 'semi-structured' interview approach to explore the sequence of 12 'digging questions', concerning stakeholder problem perception and possible solutions, listed below. In view of the likelihood of the PEK survey having to most cover larger numbers of respondents (i.e. longer list of stakeholder categories to be replicated over 2 to 3 districts), tentative conclusion was reached that PEK interviews most probably will be limited to a rapid coverage of questions 1. to 7. only, due to shortage of time available per interview.

Is there a real and important problem?

1. *What is the problem & since when does it manifest itself?*
2. *What(human activities, natural phenomena) is causing the problem?*
3. *Who (actors) is causing the problem?*

4. *Who is affected by the problem?*
5. *How bad is it for those affected?*

6. *What can be done to stop/ reduce the problem?*
7. *How do we know that this solution will work?*

8. *What effort and cost does this solution require from whom?*
9. *Why hasn't this solution been implemented yet?*
10. *Why do we think it will work this time?*
11. *Who will have to contribute to the cost?*
12. *How do we build a platform to get effective change*

[3] From review of reports focusing on the water resources of the upper Indragiri and the downstream environmental impacts of the Singkarak Hydro-Power scheme, it was decided that the downstream Ombilin river extent of the PEK survey should be at least up to the confluence with the Selo River (a significant river with similar discharge to the Ombilin), yet definitely not beyond the confluence of the Sinamar River (a much larger river basin than the 'upper Ombilin'). This boundary was estimated as the likely downstream limit of hydrological impact of the Singkarak hydro-power scheme.

E. Further review of the RHA project guideline found the prescribed framework for 'exploration of eco-hydrological terms and explanatory knowledge' revolving around analysis the of 'who benefits from what' and 'land use logic and choice' to be designed largely for the more detailed and spatially confined LEK survey, and limited to focusing only upon land use impacts upon catchment function. Conclusion was reached that the interview framework for the PEK survey would have to differ. It would need to include a broader scoping analysis of the relative impact of land use, PLTA hydro-electric scheme and other catchment developments, upon upper catchment function, lake and the downstream environments. It need to analyse 'who was impacting' (who benefits) and 'who was impacted' (who loses) for each impacting development identified. It would have to be further defined in the field after scoping assessment to define which environmental issues are of significance in which part of the river basin.

2.5.4 Stage 4: Stakeholder and Issue Identification

A. In follow-up to the tentative stakeholder identification process conducted during the scoping phase, stakeholder and issue identification continued as an 'on-ground' scoping exercise within the lake basin and province during the 1st. week of field survey.
B. Visits to the regional (Hydro) Electricity Generating Corporation (PLN), and to five provincial-level government agencies (i.e. the planning (BAPPEDA), forestry (BPDAS and Dinas Kehutanan), water (Kimpraswil – PSDA), environment (BAPPEDALDA) and land registration (BPN) agencies), and meetings with 19 senior managers were conducted over a 4 day period. Primarily to obtain hydrology, climatic, water quality, regional planning zonation, Nagari boundary and land use data. However, also in effort to gather background provincial-level information regarding previous reports, studies, issues and key stakeholders relating to water, land and environmental management of the Singkarak lake basin.
C. The above provincial-level interviews were supported by a further 2 days reconnaissance of the lake basin. One day focusing upon the PLN hydro-electricity power scheme, and infrastructure around the lake and 'downstream' within the Anai River basin (i.e. hosted by PLN field staff). With aim to view and discuss the impact of the scheme upon the lake, and the downstream Anai and Ombilin rivers on-ground. A further day of transect drive from the upper south western and southern limits of lake basin, via Solok town, down the southern. With aim to rapidly view and record (digital photos) the range of differing landscape, land use, hydrological and climatic zones of the lake basin. The object of both reconnaissance tours was to check the current field-level reality as compared to interview results and previous reported conditions.
D. The checklist of stakeholder groups for interview were subsequently finalized in follow-up discussion with well-informed the local leaders and residents - i.e. the Wali Nagari Paninngahan, the project team leader and Dr. Alimin Djisbar, local resident Paninngahan and project sub-leader. The list included the following 8 stakeholder 'categories' (at provincial, district and community level) and 21 stakeholder sub-categories (divided according to livelihood, technical focus and administrative levels), including both government (administration, agency and corporation) and community (public) stakeholders:

Provincial-level (West Sumatera Province):

- ***government agencies and corporations -*** *planning (BAPPEDA), forestry, water (PSDA), environment (BAPPEDALDA), agriculture, fisheries and land registration (BPN) agencies and the electricity generating authority (PLN);*

District-level (lake and catchment) (Solok and Tanah Datar Districts):

- ***administrative leaders –*** *Bupati, Camat, Wali Nagari and Wali Jorong;*
- ***government agencies and corporations -*** *planning (BAPPEDA), forestry, water*

(Kimpraswil), environment (Mining and Environment), agriculture, fisheries and health agencies, and the drinking water supply authorities (PDAM); and
- **public –** *sub-catchment residents and lake fishermen*

<u>District-level (urban) (Solok and Padang Panjang Municipality):</u>
- **government agencies and corporations –** *physical planning and rubbish collection agency (Kimpraswil), and the drinking water supply authorities (PDAM)*

<u>District-level (downstream) (Tanah Datar District and Sawahlunto Municipality):</u>
- **administrative leaders –** *Camat;*
- **agencies –** *water / irrigation (PSDA, Public Works), agriculture and fisheries agencies;*
- **public –** *farmers and river fishermen*

E. A guiding checklist of discussion topics relevant to water resource, landscape and environmental management was subsequently defined to act as a guide to the 'semi-structured' interview process. The range of topics covered is listed below - with variation in the interview content depending upon physical location (urban, catchment, lake or downstream), and technical / livelihood orientation of the informants.

<u>Institutional Coverage</u>:
- *Institutional responsibility; staffing levels and area of coverage; and*
- *Specific data search – for land development zonation maps, land use maps, nagari boundaries, climatic data, water quality and quantity data, and environmental reports.*

<u>Catchment Conditions and Water Supply</u>:
- *The big issues with water and landscape management?;*
- *Water supply and catchment function differences between sub-catchments; floods; dry season shortages; general stability of flow; long term trends; problem areas; cause of problems; influence of landscape; role of forest & land use;*
- *water quality, sedimentation, erosion and landslides;*
- *catchment rehabilitation schemes; current and past coverage and likely effectiveness.*

<u>Fishery and Lake Conditions</u>:
- *lake condition and water quality;*
- *fish stocks, fishery management and fish ecology (i.e. Ikan Bilih); and*
- *long term trends in lake condition and fish stocks.*

<u>Impact of PLTA Hydro-Power Scheme Development</u>:
- *general perception of impact of the PLTA scheme since 1998 development;*
- *specific impact upon lake conditions;*
- *specific impact on fishery and fish stocks (i.e. especially Ikan Bilih);*
- *downstream impact on water use patterns and fisheries.*

<u>Other Impacting Developments in Lake Catchment</u>:
- *review of developments and projects other than the hydro-scheme – i.e. plantations, mining, industry, solid waste handling, urban development and irrigation schemes.*

<u>Water Use Patterns</u>:
- *general water demand and water use profile (within the lake basin and in downstream Ombilin areas);*
- *current sufficiency of supply; and impact of changes in supply; and*
- *long term trends in both water demand and supply.*

2.5.5 Stage 5: Knowledge Articulation

A. The logistical planning and design of the follow-up interview schedule followed designed to fit within a 10 day interview schedule at district-level, covering the two lake basin districts (Solok and Tanah Datar), major lake basin towns (Solok and Padang Panjang) and downstream areas on the Ombilin river.

2.5.6 Stage 6: Data compilation and preliminary analysis

A. The hand written interview notes were later typed-up, cross-checking where possible when two interviewers were simultaneously taking notes.
B. Data from all stakeholder interviews and discussions were written up by topic with attempt to compare between different stakeholder groups. Cause-effect diagrams and other information are intended to be prepared.

2.6 Modellers Ecological Knowledge (MEK)

The objective of Modeller/Scientist Ecological Knowledge (MEK) in RHA activities :

1. Compiling data (water suply and demand) and past studies (simulation modeling) on Singkarak watershed
2. Consulting with Hydro Electric Power Plant (HEPP) to collect information on water management system for electricity generation
3. Assessing the impact of changing land use and land cover on Singkarak watershed using the hydrological model (GenRiver)
4. Synthesizing data, information and result of hydrological simulation analysis

2.6.1. Basic concepts

Key 'watershed functions', such as the volume and timing of water flows from a landscape, depend primarily on the way incoming rainfall is partitioned over

1) canopy ***interception*** by the vegetation, modifying the rate at which water reaches the ground and leaving a thin film of water on the leaf surfaces, ready for ***evaporation*** soon after the rainfall event,
2) overland flow of water that can not infiltrate the soil surface rapidly enough ('***surface quick flow***') and finds its way to streams and rivers within a few hours of the rainfall event,
3) rapid water flows through the soil of water ('***soil quick flow***') that can infiltrate but that cannot be held by the soil at 'field capacity' (this may happen on a time scale of hours to day(s))
4) water taken up by plant roots from the soil and used for ***transpiration***, creating new pore space for infiltration (evaporation from bare soil surfaces can be included in this under the heading ***evapotranspiration***)
5) water that seeps from groundwater stocks gradually into streams and river ('***base flow***').

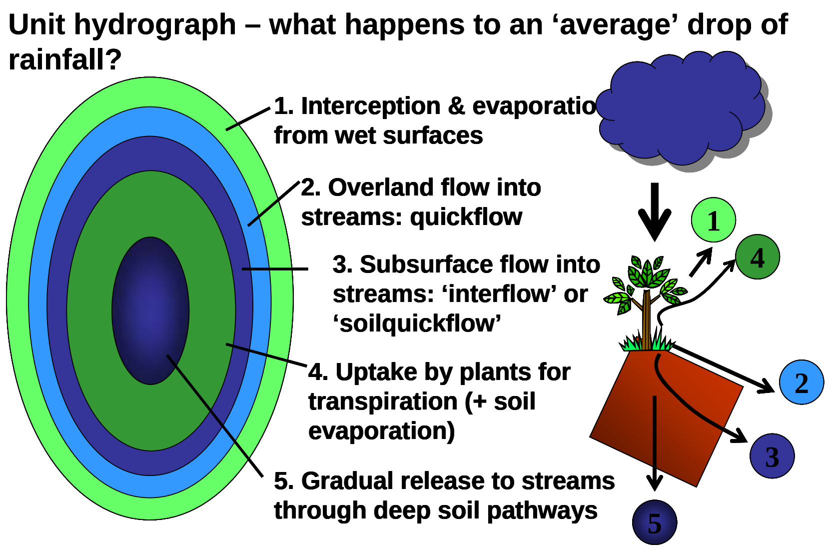

Figure 2.15. The main pathways of water and the way incoming rainfall can be allocated to 5 ways of leaving a patch of land

A simple water balance can be constructed that shows that

$$P = \Sigma Q + \Sigma E + \Delta storage$$

Where:

P = precipitation (which ion the tropics is essentially rainfall), conventionally measured in mm day^{-1} or l m^{-2} day^{-1},

ΣQ = sum of stream, river and groundwater flows (originating as surface quickflow, soil quick flow or base flow), converted from the flow rate measures $m^3 s^{-1}$ to mm day^{-1} through division by the size of the source area,

ΣE = sum of all forms of evapotranspiration (canopy intercepted water, transpiration by vegetation, evaporation from bare soil), conventionally measured in mm day^{-1} or l m^{-2} day^{-1},

Δstorage = changes in storage of water in the soil, groundwater stocks, rivers or ponds and lakes, measured in mm day^{-1}.

At a sufficiently long time scale (say for an annual balance) the change in storage may become negligible, and total river flow can be estimated from total rainfall minus total evapotranspiration. The latter is constrained by the energy balance of incoming solar radiation, with corrections for 'lateral flows' of dry air through wind speed and air humidity.

Impacts of land cover change on watershed functions (at least the functions linked to volume and timing of flows) may, in this scheme, be attributed to:

- changes in ***canopy interception*** depending on the total amount of leaf surface and the potential thickness of water films on these surface,
- changes in ***evapotranspiration*** that depend on the phenology of the vegetation (especially on the parts of the year that there is a green leaf canopy),
- changes in the capacity of the ***soil*** to absorb water, modifying the partitioning over surface quick flow, soil quick flow and base flow
- changes in the ***landscape drainage*** pattern that influence the rate at which water flows are delivered downstream.

The first two effects will influence the total amount of water that becomes available as river (+ groundwater) flows, the last two influence its partitioning over the various flow pathways and hence the timing of its appearance in streams and rivers.

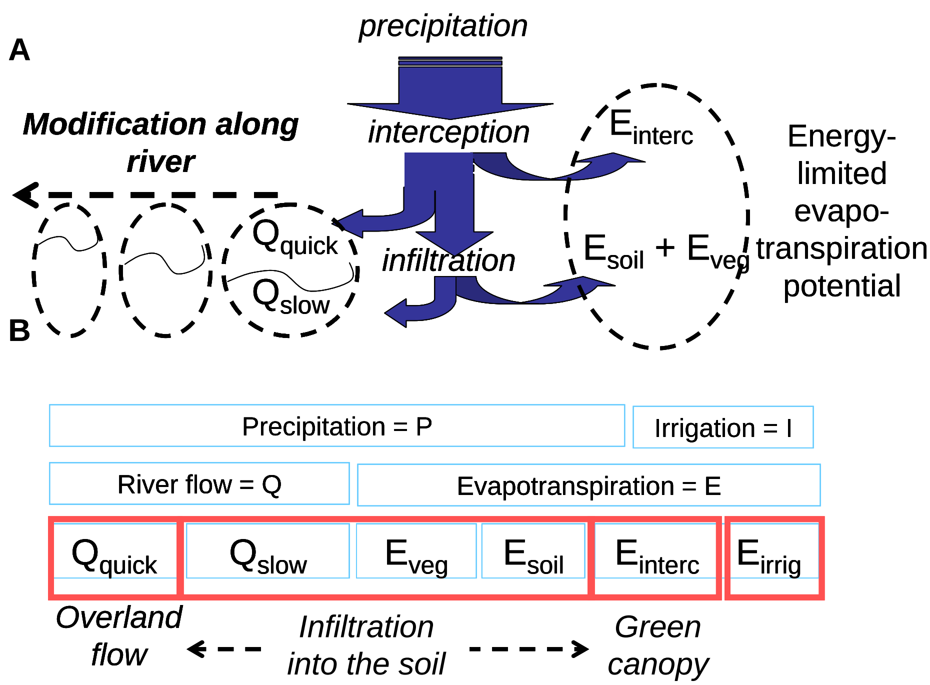

Figure 2.16. Schematic view of the water balance and the way precipitation (P) can be partitioned over evapotranspiration (E) and river flow (Q)

Potentially land cover change can also influence the water balance through effects on rainfall (P), but the scale at which such effects occur is still much debated. While land cover change is linked to global climate change with feedbacks to local rainfall (both increases and decreases have been recorded at decadal time scale depending on position relative to the global circulation systems), effects on rainfall at a more local scale remain uncertain. There is an increasing body of evidence on effects of vegetation and especially 'forest edges' on thunderstorm development and hence on the temporal distribution of rainfall, evidence for effects on total amount is weak. Effects are likely to be below 10% of total rainfall and are hence difficult to distinguish from the 'normal' variability of rainfall.

2.6.2 Changes in hydrology of Lake Singkarak due to the HEPP

The hydrology of the Singkarak Lake and catchment before the start of the Hydro Electric Power Plant (HEPP) can be studied in two parts: the upland areas contributing overland and groundwater follows to the lake in response to rainfall, and the outflow from the lake into the Ombilin river, jointly determining the fluctuations in the level of the lake. The HEPP scheme has drastically modified the second part, but not the first. In this study we are mainly interested in the influence of land use (and its resultant land cover) in the 'catchment' area on the fluctuations in the lelevl of the lake and the performance of the HEPP scheme.

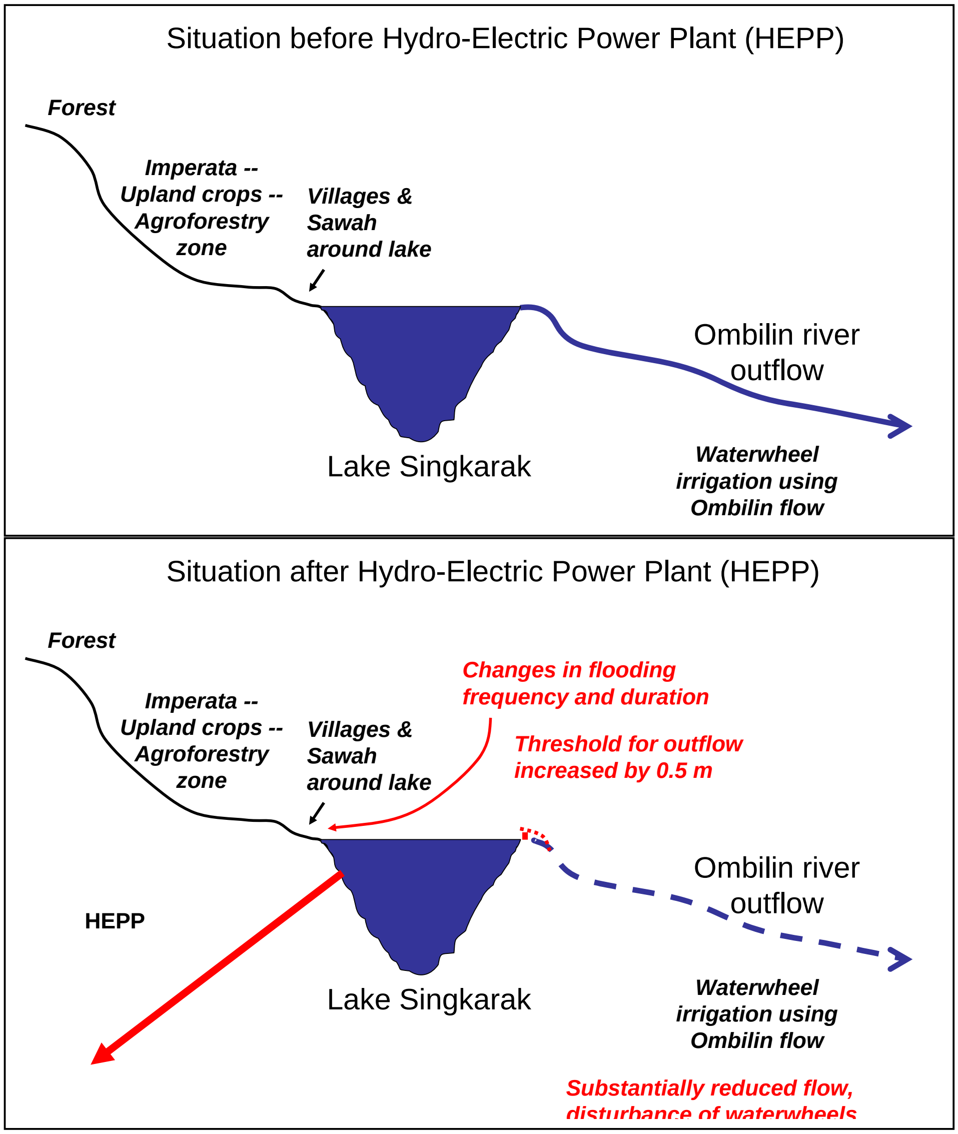

Figure 2.17. Cross section of the landscape of Lake Singkarak and the main changes that the hydro-electric power plant (HEPP) scheme brought to the hydrology of the area

2.6.3 Required model structure: adapting GenRiver

The basic principles of rainfall, patch-level partitioning of flows and the integration of the various flows in a stream network are applied in various simulation models. Models vary in their data requirements and in expected precision of the results. In data-rich environments a fully empirical model may be constructed that can be used for interpolation and extrapolation to scenarios that do not differ drastically from the conditions that were used to parameterize the model. Where less data are available or where we want to explore scenarios that differ substantially from the recent past, a stronger reliance on 'first principles' is needed. If there is only limited opportunity to 'calibrate' or 'tune' such a model, we cannot expect a high level of precision of the model predictions, but we may still use the model for the direction and relative size of impacts of future changes under various scenarios. The existing models differ in the modelling platform (language) they use and in the ease with which they can be modified at the level of parameters or model structure. Here we will use the GenRiver model developed by ICRAF, as it is based on simple principles, its parameter requirements are adjusted to what is generally available from 'secondary data' and it uses the Stella platform in which modifications of model structure are relatively easy to implement.

The steps involved in MEK activity :

Stage	Methods	Expected Outcomes
Stage 1 : Literature review on hydrological, landscape, geological, climate and water management system and operating rules for HEPP	Collecting information from past studies and HEPP	Setting of Singkarak watershed and HEPP water management
Stage 2 : Parameters for climate and hydrological time series data and other climate data	Time series data analysis	Climatic and hydrological description of Singkarak watershed
Stage 3 : Parameters for land use/land cover and river network	Geospatial data processing and analysis	Baseline spatial data Model indicators
Stage 4 : Parameters for baseline soil parameter (type and depth)	Information from current and past studies and exisiting soil map	Model indicators
Stage 5 : Parameters and analysis for current and plausible land use change scenarios	Using hydrological model (GenRiver) for several land use change scenarios	Hydrological impact of land use changes in Singkarak watershed

Stage 1 : Literature review on hydrological, landscape, geological, climate and water management system and operating rules for HEPP

A. Desktop collecting information from past studies specially on hydrology, landscape, geology, climate. Initial data collection by searching in internet for various topics as mentioned above.
B. Consulting with HEPP to collect information on water management system for electricity generation

Stage 2 : Parameters for climate and hydrological time series data

A. Data mining for location- spesific rainfall and river flow (debit) records.
B. Data mining for potential evapotranspiration
C. Data mining for other climatic records
D. Analyze data consistency

Stage 3 : Parameters for land use/land cover and river network
See 'Spatial analysis' section (2.3)

Stage 4 : Parameters for baseline soil physical parameters

A. Compiling and interpretation soil physical paramaters information from past studies and exisiting soil map specially for soil type and depth.

B. Apply pedotransfer function for various soil type as parameters for the GenRiver model The spesification of clay, silt, organic matter content and bulk density of various soil types taken from Suprayogo (2003) pedotransfer database for tropical soil. Pedotransfer function (Wosten et al, 1998) as adapted from WaNuLCAS model is used to derived saturated soil water content, field capacity and permanent welting point. These parameters are used in the GenRiver model for integrated soil water content.

Stage 5 : Parameters and simulation analysis for current and plausible land use change scenarios

A. GenRiver adjustment for watershed and lake application
GenRiver is a generic model of river flow in a catchment that is subdivided in subcatchments with separate dynamics of land cover change and rainfall, and different properties for soil parameters and routing distance if desired. The model was developed as a tool to analyze river flow due to the land use change in two catchments in SE Asia: the Way Besai (Sumberjaya) watershed in Lampung Indonesian and Mae Chaem in Northern Thailand; default input parameters are based on the Sumberjaya case.

The model treats a river as a summation of streams, each originating in a subcatchment with its own daily rainfall, yearly landcover fractions and constant total area and distance to the river outflow or measurement point. Interactions between streams in their contribution to the river are considered to be negligible (i.e. there is no 'backflow' problem). Spatial patterns in daily rainfall events are translated into average daily rainfall in each subcatchment in a separate module. The subcatchment model represents interception, infiltration into soil, rapid percolation into subsoil, surface flow of water and rapid lateral subsurface flow into streams with parameters that can vary between land cover classes.

In order to be able to apply Singkarak watershed condition using the model, we had to put several new adjustments such as :

1. Lake application into the model.
   Lake is treated as a cumulative pool for streams from various subcathments. Lake as a dynamic reservoir has several properties such as evaporation, lake volume and area, lake flooding volume and overflow fraction.
2. HEPP application into the model
   HEPP is taking water regularly from the lake for electricity generation. HEPP water management such as HEPP daily demand and critical volume.
3. River outflow from the lake

B. GenRiver parameterization
A new GenRiver application for different watershed, we need to the following data :

1. Climate
   - Rainfall
     A number of formats are possible, as long as they allow a reconstruction of monthly exceedance curves of daily rainfall intensity:

     - daily rainfall records for a station that can represent the area (or multiple stations if these are supposed to be similar). We used Sumani and Saning Bakar daiyly rainfall records from 1990 – 2002.

   - Rainfall intensity
     Data on rain duration and amount for a sampling period that is deemed representative to estimate the mean and coefficient of variation of rainfall depth per hour.

- Rainfall spatial correlation (SpatRain module)
  An indication of the degree of spatial correlation in rainfall (correlation coefficient of daily rainfall as function of distance between stations), or of the generic nature of rainfall (frontal rains with high spatial correlation or convective storms that are 'patchy' and show low correlation). We used generated spatial distributed rainfall from SpatRain module since we did not have representative rainfall data for all subcatchment in Singkarak watershed.

- Potential evapotranspiration
  Average values per month, derived from UNEP/GRIP document summary for monthly potential evapotranspiration. This compilation was published by CH Ahn and R. Tateishi in 1994. While for Singkarak watershed we have used potential evapotranspiration data from Singkarak HEPP Project Completion Report volume IIA.

2. Landform and river network
   DEM that allows for derivation of overall difference in elevation within the subcatchment, and a delineation of subcatchments (details as mentioned in stage 3.C).

3. Soils

   - Mean soil depth (till major restriction for root development)
   - Average texture (or soil type in a way that allows texture to be estimated) as input to 'pedotransfer' functions to estimate soil water retention curve (saturation, field capacity, wilting point)
   - Estimated bulk density relative to the reference value for soils under agricultural use, to estimate saturated hydraulic conductivity and potential infiltration

4. Geology

   We need to estimate the 'differential storage' in 'active groundwater' as well as a 'groundwater release' fraction. So far these parameters were 'tuned' to the recession phase of actual riverflow during periods without rainfall. In the absence of such data we will need to 'guesstimate'. If data on the seasonal variation in depth of groundwater table are available, we can use those.

5. Vegetation and land cover

   Vegetation and land cover fraction from satellite image-derived. Eight different land cover classes had been classified in Singkarak watershed (details in Stage 3B).

6. Actual river discharge

   If available, river debit data for any period of time (expressed in $m^3 s^{-1}$ in the river or mm day^{-1} over the whole contributing catchment) will be valuable in 'constraining' the simulations. If not available, we will simply have to 'believe' the model predictions as such. For Singkarak watershed we have Batang Sumani daily river discharge for 1992-2002.

C. GenRiver simulation for current and plausible land use change scenarios.
   GenRiver simulation for land use change scenarios can be divided into :
   1. Simulation using current land use scenario from satellite image-derived land cover for parameterization and model validation
   2. Simulation using plausible land use change scenarios such as :
      - All subcatchments covered by forest
      - All subcatchments covered by grassland (degraded land)
      - 50% increment of existing land use from each subcatchment

D. Model simulation analysis for current and plausible land use change scenarios.
   A set of quantitative indicators was developed for the first three criteria (Table 2.4), that can make use of long term records of rainfall and river flow, and/or be used to summa

rize results of simulation models.

Using quantitative watershed function criteria and indicators (table 2.5) in analyzing output of river flow and water balance for current and plausible land use change scenarios.

Table 2.5 Quantitative watershed function indicators

Criteria	Indicator
1. Transmit water	*Total water yield (discharge) per unit rainfall(TWY)* $TWY = \Sigma Q/(A * \Sigma P)=1-(\Sigma E/\Sigma P)$ Q = river discharge P = rainfall A = area E = evapotranspiration
2. Buffer peak rain event	*a).Buffering indicator for peak flows given peak rain events (BI)* $BI = (P_{abAvg}-(Q_{abAvg}/A))/P_{abAvg}$ $= 1 - Q_{abAvg} / (A\ P_{abAvg})$ *with* $P_{abAvg} = \Sigma \max(P-P_{mean},0)$ $Q_{abAvg} = \Sigma \max(Q-Q_{mean},0)$ ***b). Relative buffering indicator, adjusted for relative water yield (RBI)*** $RBI = 1 - (P_{mean} / Q_{mean})*(Q_{abAvg} / P_{abAvg})$ ***c). Buffering peak event (BPE)*** $BPE = 1-Max(daily\_Q-Q_{mean}) /(A*Max(daily\_P-Pmean))$ ***d). Highest of monthly river discharge totals relative to mean monthly rainfall*** *e).* ***Fraction of total river discharge derived from Surface quick flow (same day as rain event)*** *f). Fraction of total river discharge derived from Soil quick flow (one day after rain event)*
3. Realease gradually	*a). Lowest of monthly river discharge totals relative to mean monthly rainfall* *b). Fraction of discharge derived from slow flow (> 1 day after rain event)* $\Sigma Q_{slow}/(\Sigma Q) = (\Sigma P_{infiltr} - \Sigma E_{S+V})/ \Sigma Q$ with $P_{infiltr}$ = amount of rainfall infiltrated into the soil ES+V = evaporation from soil surface an d transpiration by plants

Note :

Q (mm/day) ={[***Q(m³/sec)*** x24 hourx3600 sec/hour]/[***A(km²)*** x10⁶ m²/km²)]}x10³ (mm/m)

P_{mean}	= average rainfall ;	Q_{mean}	= average debit
P_{abAvg}	= rainfall above average	Q_{abAvg}	= debit above average

3. Results

3.1 Setting of Singkarak Lake and Singkarak basin from literature review

3.1.1 Landscape, climate, geology of Singkarak basin

Singkarak Basin is located at the middle part of West Sumatera Province, Indonesian and covers an area of approximately 1135 km^2. The basin belongs to two districts (kabupaten) Kabupaten Tanah Datar in the northern half and Kabupaten Solok in the southern half. Geographical boundary of Singkarak Basin is 100.39d-100.75d Longitude and 0.3d-1.04d Southern Latitude. Map 3 (inside cover) shows administrative boundaries around Singkarak Basin and its vicinity.

The basin area generally falls under the typical humid tropic climate covering almost all of Sumatera. An agro-climatic map of West Sumatera (Oldemann et al., 1978) shows five climatic zones, composed on the basis of consecutive wet and dry months, in the basin area. Much of the subbasins areas of the Lembang/Sumani and Sumpur rivers belong to the wettest zone, while the vast majority of the subbasin area of the Ombilin River is in the driest zone, constituting around one-third of the subbasin area. Consequently, changes in the outflows from Singkarak Lake have an important impact on water availability for the subbasin area under Ombilin River.
Rainfall patterns in the basin area match the above mentioned of agro-climatic zones. Average rainfall in the subbasin area was 2,026 mm/yr. The subbasin area of the Sumpur River is the wettest, with average rainfall of 2,484 mm/yr. This is slightly higher than the Lembang/Sumani river subbasin with annual average of rainfall of 2,201 millimeters. The Ombilin River subbasin is the driest, with annual average of rainfall of 1,789 mm. Mean monthly rainy days range from 5 to 24 days, while mean annual pan evaporation and temperature range from 3.9 to 5.3 mm/day and 22.5 to 26.2^{o}C, respectively.

Information on geological properties used in this study is mainly obtained from Geological Map scale 1:250,000 published by Geological Research and Development Centre. The sheets covering Singkarak Basin are Padang Sheet (0715) and Solok Sheet (0815)

Singkarak Basin is an elongated basin from Mt Merapi in the north and Lake Danau Di Bawah in the south. It's part of the depression of Semangko faults, bound by mountainous area of Bukit Barisan in the west, and tertiary fold in the east. (Sandy, 1985) The relatively flat depression area around and south of the lake is covered by alluvial deposits of clay, sand and gravel and andesite detritus from the volcanoes.

The major underlying rocks in Singkarak Basin are volcanic rocks. Several parts in the western and northwestern part of the basin are metamorphic rocks (limestones). The plain area to the south of the lake is alluvium. Of the volcanic rocks in Singkarak Basin, both the upstream most areas in the north and in the south are breccia andesit, in the northern part being connected to Mt Merapi, while the southern most part connected to Mt Talang. See Figure 3.1 for Geological Map of Singkarak Basin.

The Lake is in a geologically active area. On June 28 1926 a major earthquake hiot the Padang uplands. Besides much damage to buildings and other structures, great parts of the beach of Lake Singkarak sank away, and depths of 10 meters were found in several places where the land was dry before. Moreover high tidal waves were formed in the lake. (Braak, 1929).

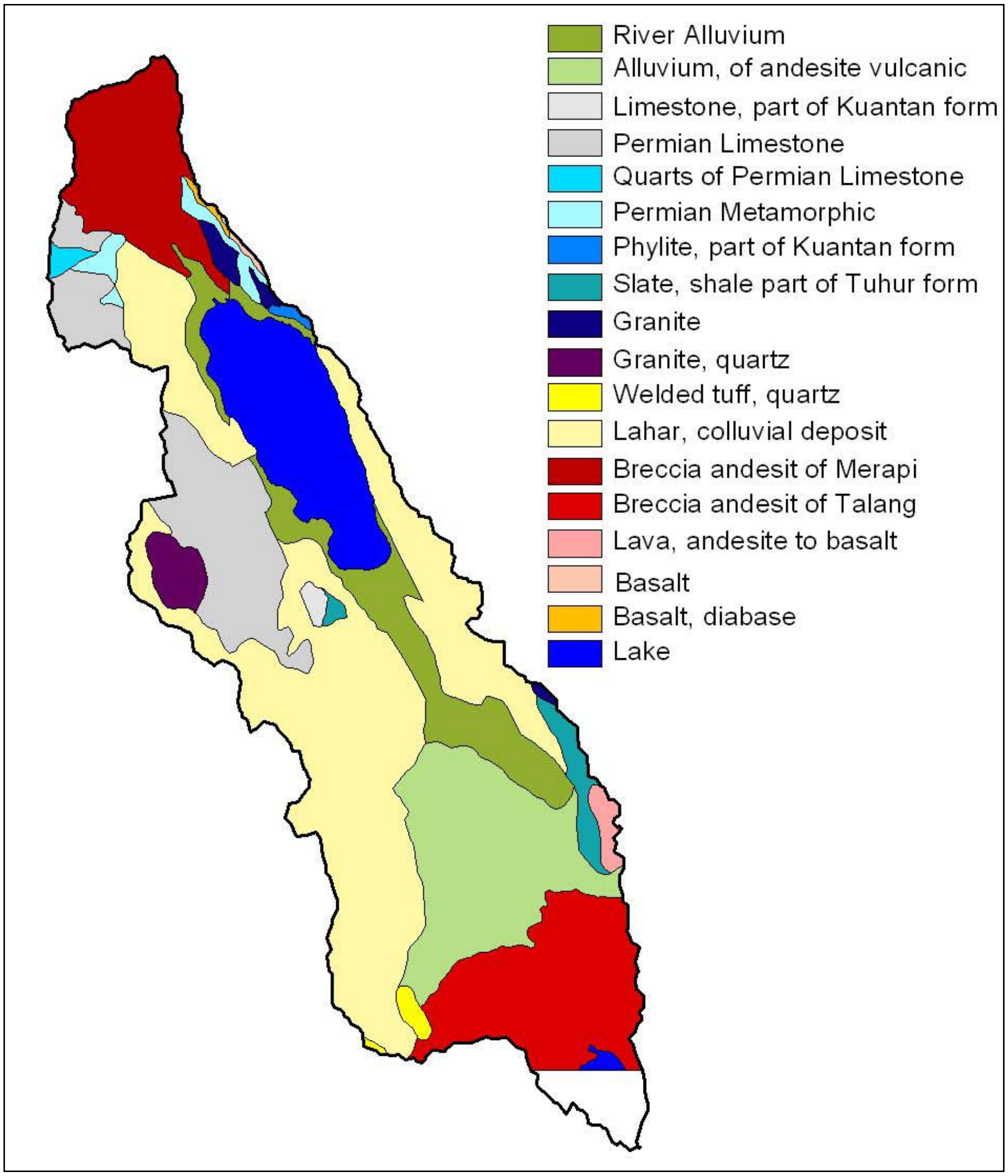

Figure 3.1 Geology of Singkarak Basin

Data source for soil information is Land Unit and Soil Map scale 1:250,000, published by Centre for Soil and Agroclimate Research The sheets covering Singkarak Basin are the same as the ones of Geology maps, i.e. Padang Sheet (0715) and Solok Sheet (0815) .

In Singkarak Basin the soils are Inceptisols (Dystropepts, Dystrandepts, Humitropepts and Tropaquepts). However, combinations with Ultisols (Paleudults, Hapludults, Haplohumults), Entisols (Troporthents, Tropofluvents) and Alfisols (Hapludalfs) occur in some parts of the basin.

The soil map generalized from Land Unit and Soil Map is shown in Figure 3.2.

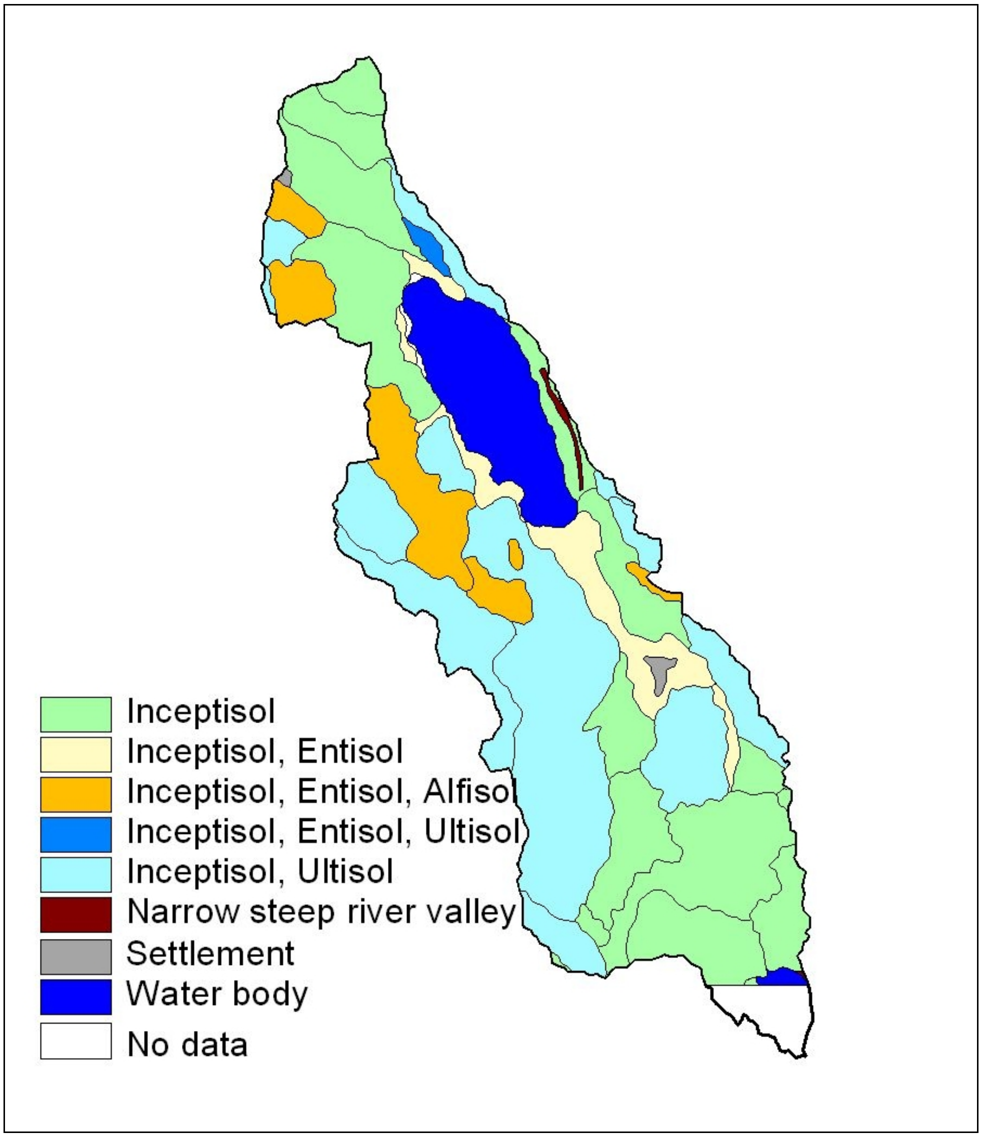

Figure 3.2 Generalized Soil Map

Slope and subcatchment definition

a. Slopes

Based on the 90 m * 90 m grid spacing of elevation grids, the slope distribution is seen in Figure 3.3.

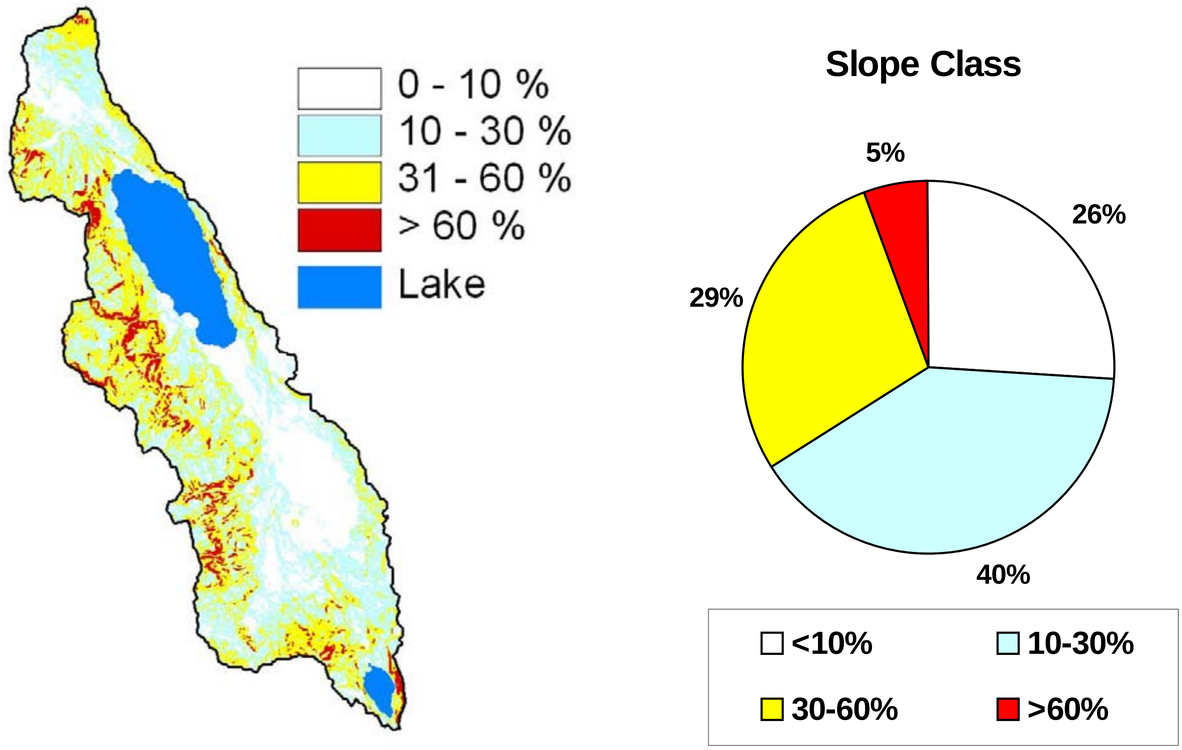

Figure 3.3 Slope distribution in Singkarak Basin

Flat areas (< 10%) are mostly located in the depression area, elongated from Padang Panjang in the north, to Solok in the south. The steeper slopes mostly occur as part of mountainous range of Bukit Barisan range and towards the peaks of two mountain in the basin tips, Mt Merapi (2891 m) in the north tip and Mt Talang (2597 m) in the south tip.

b. Hydrological attributes

The resulted basin and derived hydrological attributes from the DEM can be seen in Figure 3.4. The area of Singkarak Basin is 113,000 ha (11.3 km2).

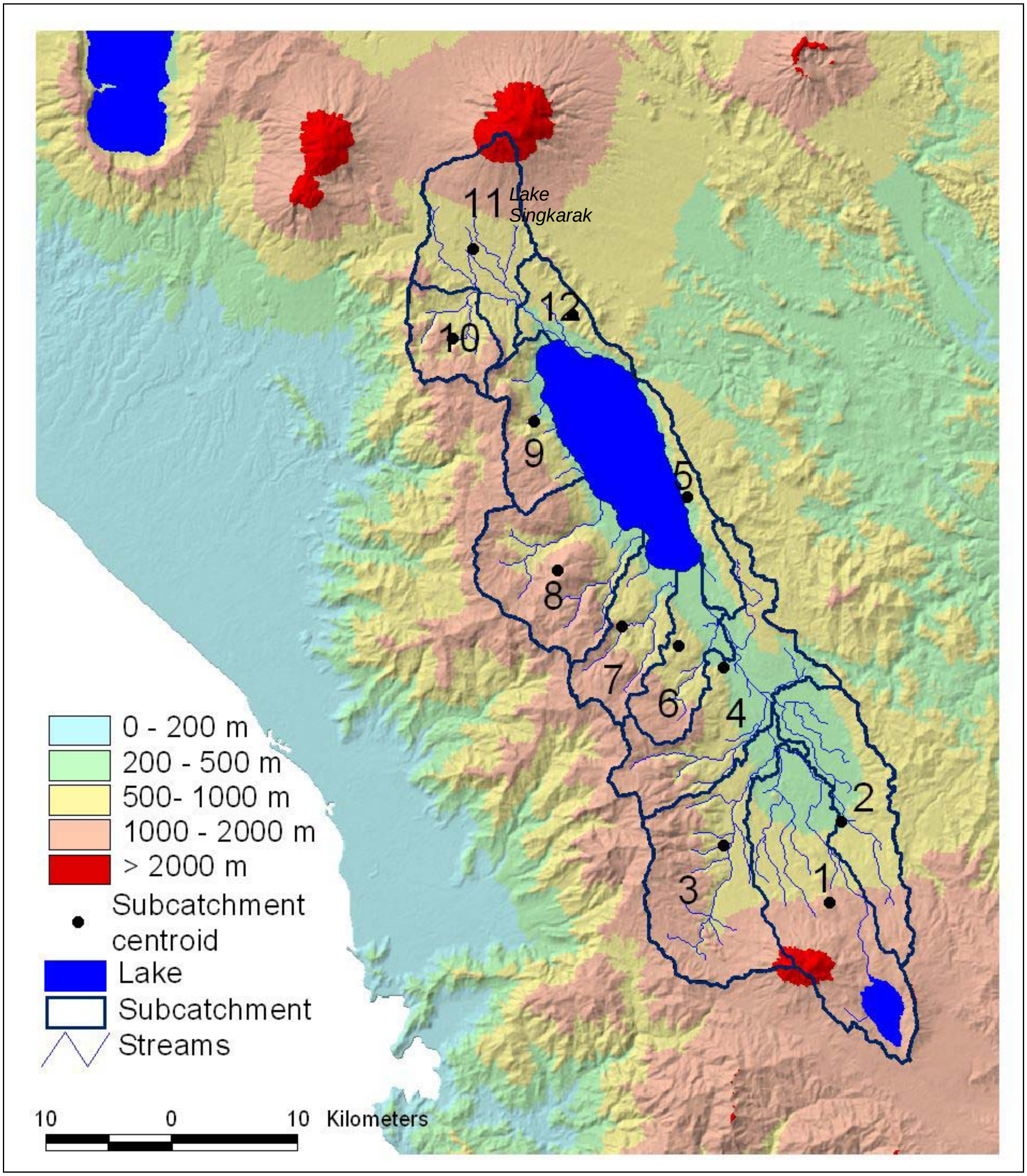

Figure 3.4 Basin, streams & subcatchments in Singkarak Basin

The number of subcatchments extracted is 12 subcatchments and the area of each Subcatchment are listed in Table 3.1.

Table 3.1 Areas of the subcatchments in Singkarak Basin

Subc. ID	Area(ha)
1	15868.392
2	9934.289
3	13880.081
4	12235.27
5	3499.936
6	5490.17
7	5986.971
8	11952.482
9	5438.427
10	4515.741
11	9842.781
12	3521.708

The routing distance of each subcatchment to the lake is shown in Table 3.2. Due to the shape of the basin and the slope length of the catchments, the longest routing distance to the lake is from the subcathment of Lake Danau Di Bawah, approximately 34 km, while the shortest is from the subcathment located in the east of the lake 700 m.

Table 3.2 Routing distance of each subcatchment to the lake

Subc_ID	Routdist2lake(m)
1	34228.646
2	28738.99
3	28336
4	10886.26
5	700
6	11683.65
7	8010.92
8	10177.03
9	2587.41
10	18941.28
11	15177.66
12	6894.9

3.1.2 SATELLITE IMAGE-DERIVED LAND COVER MAP

Land cover classification

The result of hierarchical land cover classification is a land cover map of Singkarak Basin and the vicinity, West Sumatera. Figure 3.5 shows the land cover map.

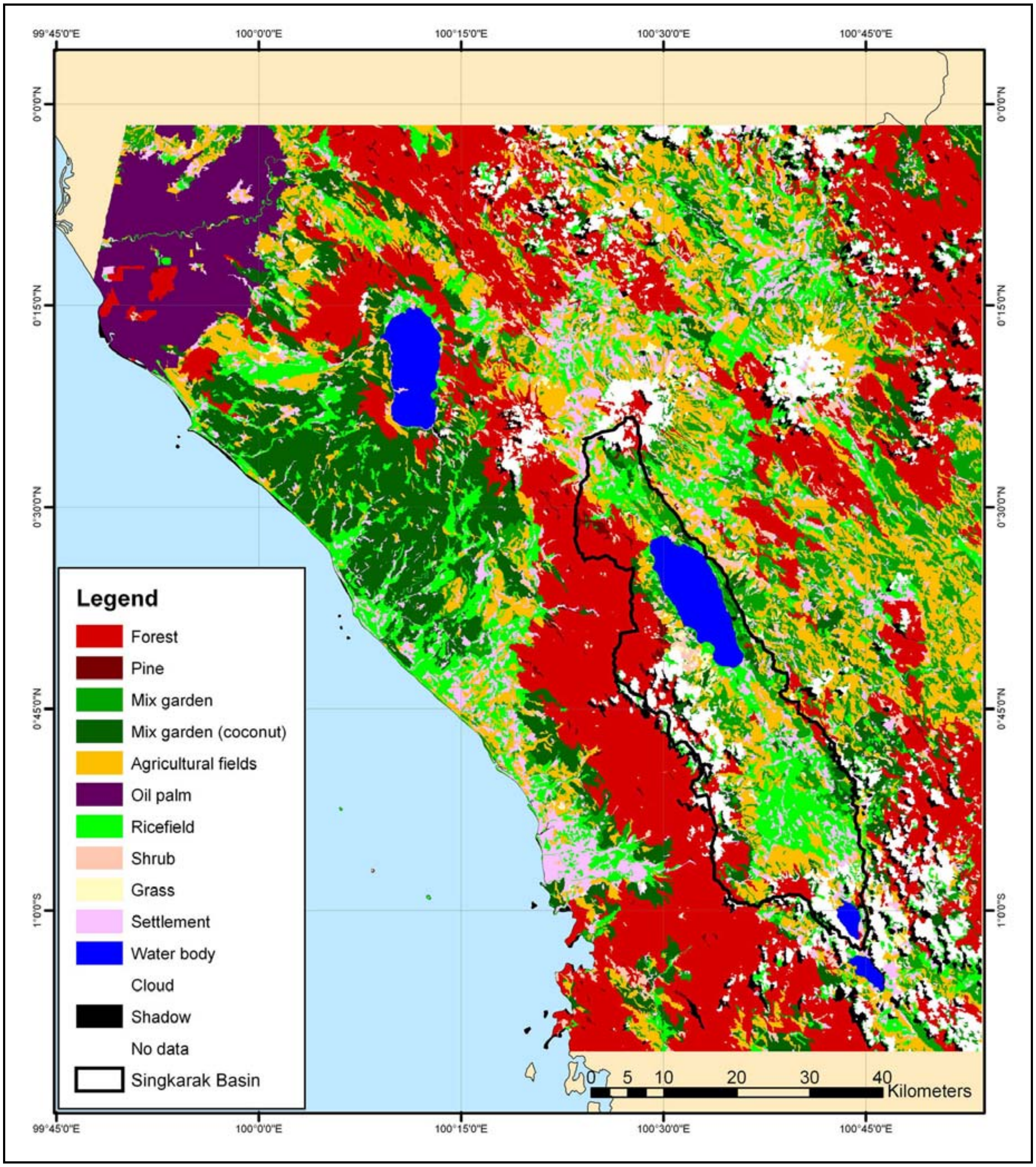

Figure 3.5 Classified Image of Singkarak Basin and the vicinity

For the subset of Singkarak Basin, the land cover areas and proportions are shown in Table 3.3 and Figure 3.6.

Table 3.3 Land cover Proportion in Singkarak Basin

No	Class name	Area (km2)
1	Forest	173.3
2	Pine	14.4
3	Mixed garden	132.7
4	Mixed garden (coconut)	54.0
5	Agricultural fields	170.6
6	Ricefield	197.2
7	Shrub	16.9
8	Grass	18.6
9	Settlement	93.7
10	Water body	119.4
11	No data	144.4
	TOTAL	**1135.3**

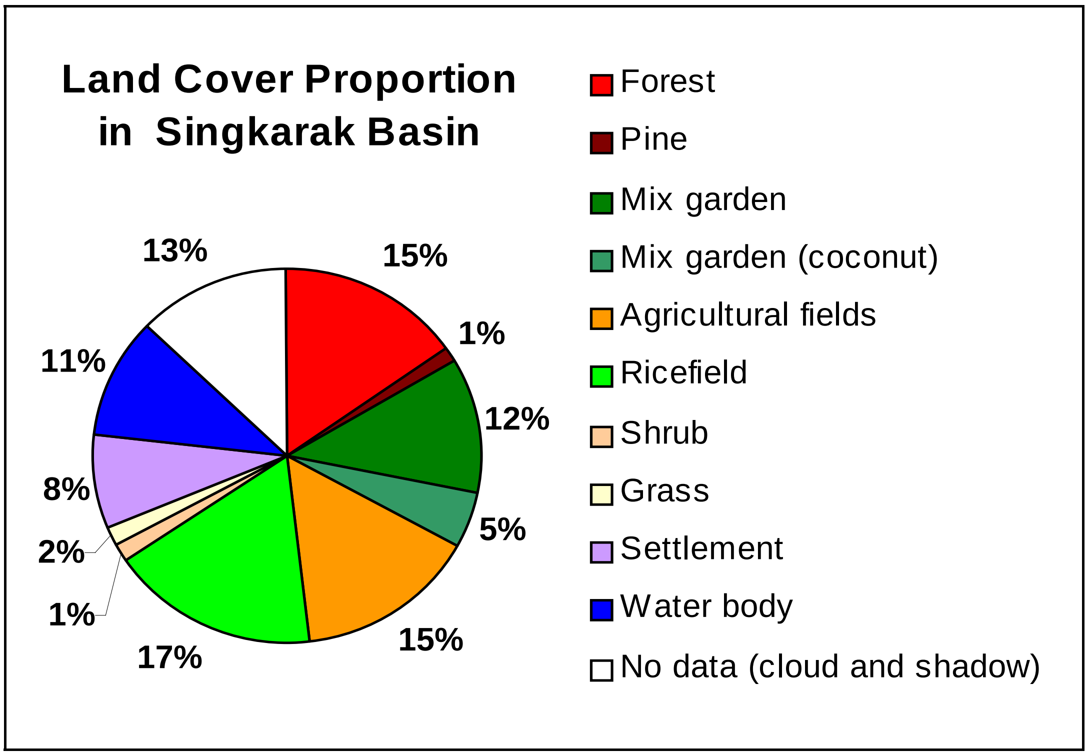

Figure 3.6 Land cover proportions in Singkarak Basin

For land cover proportion for each unit of analysis (e.g. Subcatchment and *Nagari*), the results are shown in Appendix 4 and Appendix 5. The proportion in a nagari is based on the nagari boundary located within the basin (see Appendix 3 for visualization). The proportion of each land cover type in a subcatchment is done to the whole subcatchment area, which in some cases includes cloud-covered areas (no data).

3.1.3 Accuracy Assessment

The accuracy assessment was obtained through a *classification error matrix*, often referred to *confusion matrix* or *contingency matrix*. Error matrices compare on a category-by-category basis, the relationship between known reference data (ground truth) and the correspondent results of an automated classification. Parameters which indicate the accuracy of land cover map include overall accuracy, user/producer's accuracy and Kappa value.

Ground truth

Ground truth was conducted to collect reference data, which were used in accuracy assessment. A week of field survey was spent to collect Global Positioning System (GPS) points of all land cover types classified in satellite image. Stand-alone Trimble GeoExplorer II was used for the ground truth. Geometric precision relative to satellite image is approximately 20 m. All reference data were taken in a minimum of 30x30 m homogenous area. A total of 333 reference points were collected during fieldwork.

Accuracy Assessment Result

By comparing reference dataset to the classified image, one can produce an accuracy matrix which gives the **indication** of the accuracy of the land cover map. Table 3.4 shows the accuracy matrix for Singkarak Basin land cover map.

Table 3.4 Accuracy matrix of Singkarak Basin land cover map

Classified	Reference								
	Forest	**Pine**	**Mix1**	**Agri**	**Rice**	**Shrub**	**Grass**	**Settl**	**Totals**
Forest	44	0	2	0	0	0	1	0	47
Pine	4	7	0	0	0	0	0	0	11
Mixed garden	9	2	81	1	2	0	0	1	96
Agri	0	0	6	40	1	1	0	1	49
Rice	0	0	5	2	43	1	1	4	56
Shrub	0	0	3	0	0	20	2	0	25
Grass	0	0	0	0	0	2	17	0	19
Settlements	0	0	0	1	3	1	3	22	30
Totals	57	9	97	44	49	25	24	28	333

Overall accuracy of the land cover map is 82.2% while Kappa value is 79%. Most confusion/misclassification happens between classes of agricultural field-ricefield-mixed garden. Another minor confusion also occurs between pine and forest. Based on the reference data collected during ground truth, the accuracy indication of the land cover classes (table 3.5) was lowest for the pine forest.

Table 3.5 Accuracy of Singkarak Land cover Map

Class	Accuracy (%)
Forest	0.94
Pine forest	0.64
Mixed garden	0.84
Agriculture	0.82
Rice	0.77
Shrub	0.80
Grass	0.89
Settlement	0.73

3.1.4 LANDSCAPE IN SINGKARAK BASIN

Land Cover

From Figure 3.6 it was seen that the major landuse in Singkarak Basin are ricefields (17%), agricultural crops (15%) and Forest (15%).

Ricefields occur in the lowland area, below 1000 m asl and with the slopes of < 30%, commonly found in the southern part of the basin, around Solok, and in smaller extent in the area north of the lake, around Simbur/Padang Panjang. The underlying rock of these areas are alluvium for those in the south and breccia in the north, but both are originally from andesite volcanic. Besides rice, other types of agricultural crops are also found in the lowland plain around Solok to the south around Cubak/Mt Talang up to > 1000 m asl. In this higher elevation area, the crops are mostly **vegetables**, having long been the main cultivation in the area.

Other land cover types like **mixed gardens , coconut-based mixed garden, shrubs and grass** are found in smaller patches all over the basin. In the higher elevation (> 1000m asl) and where slopes are steeper (>30%) along the western range of the basin -- parts of Bukit Barisan-- and in the upslope of Mt Merapi, **forest** is the dominant land cover type. Patches of **pine forest** are found in Bukit Barisan range above Paninggahan and Batuipuh.

Terrain and Slopes

The relatively flat areas **(< 10% slopes)** covering 26% of the area are mostly in the lower elevation (<500 m asl), around Solok, and are mostly cultivated with rice, while in higher elevation (>500 m asl), e.g. around Padang Panjang , vegetable crops are commonly planted as well. The major slopes in Singkarak Basin are **slopes of 10-30%** (40% of the area). These slopes mostly occur in the foothills in the west, in the south (of Mt Talang), and in the north (of Mt Merapi). Agricultural lands like mixed gardens, vegetables are still found in this slope class, below 1000 m asl. In the higher elevation in Bukit Barisan (> 1000 m asl) forest dominate this slope class. Combination of steep slopes (**30% up to 100%**) appears as dissected plateau in the west side of the basin. These very steep areas are covered by natural vegetation like forest, shrubs and grass, also patches of less intensive agricultures, like mixed gardens.

From the perspectives of the underlying rock, the fertile **alluvium**-covered depression areas, located around the lake and in the south (Solok up to Cubak), which mostly coincide with low elevation (< 500 m asl) and flat slopes (< 10%), are unsurprisingly dominated by the most intensive agricultural lands, i.e. ricefileds and patches of vegetables. The most vast underlying rocks, **volcanic rocks covered by colluvium deposits**, which coincide with steeper slopes (> 10%) and elevation >500 m asl, are located along the western and eastern parts of the basin. These areas are dominated by vegetables and mixed gardens, and in the higher elevation (> 1000 m) by forest. The other **volcanic rocks, breccia andesit ,** occurs around Padang panjang and at the hills of Mt Talang and Lake Danau di bawah, and has major land covers of intensive agricultures like vegetables and ricefileds. **Limestones** located in the western and northwestern parts of the basin are dominated by forest and patches of grass and shrubs and so are the **granite** areas in the west border of the basin.

Drainage areas

The upstream areas of Singkarak Basin can generally be divided into three (See Figure 3.7) :

a. Southern upstream (from Lake Danau di Bawah and Mt Talang)
b. Western upstream (from Bukit Barisan)
c. Northern upstream (from Mt Merapi)

a. Southern Upstream

This upstream area is characterized by longer slopes thus longer streams and before they reach the lake, they pass the flat downstream area around Solok (Batang Sumani). The streams originating from Lake Danau Di Bawah flow northward towards the main streams of Batang Lembang, and in the plain south of Solok, it joins Batang Sumani, a main tributary from Mt Talang, which becomes the main and biggest river flowing to the lake.

The land covers in this upstream area are quite dominated by intensive agricultural fields: ricefields and vegetables, which are well supported by the favorable alluvium, and the dominating flat slopes.

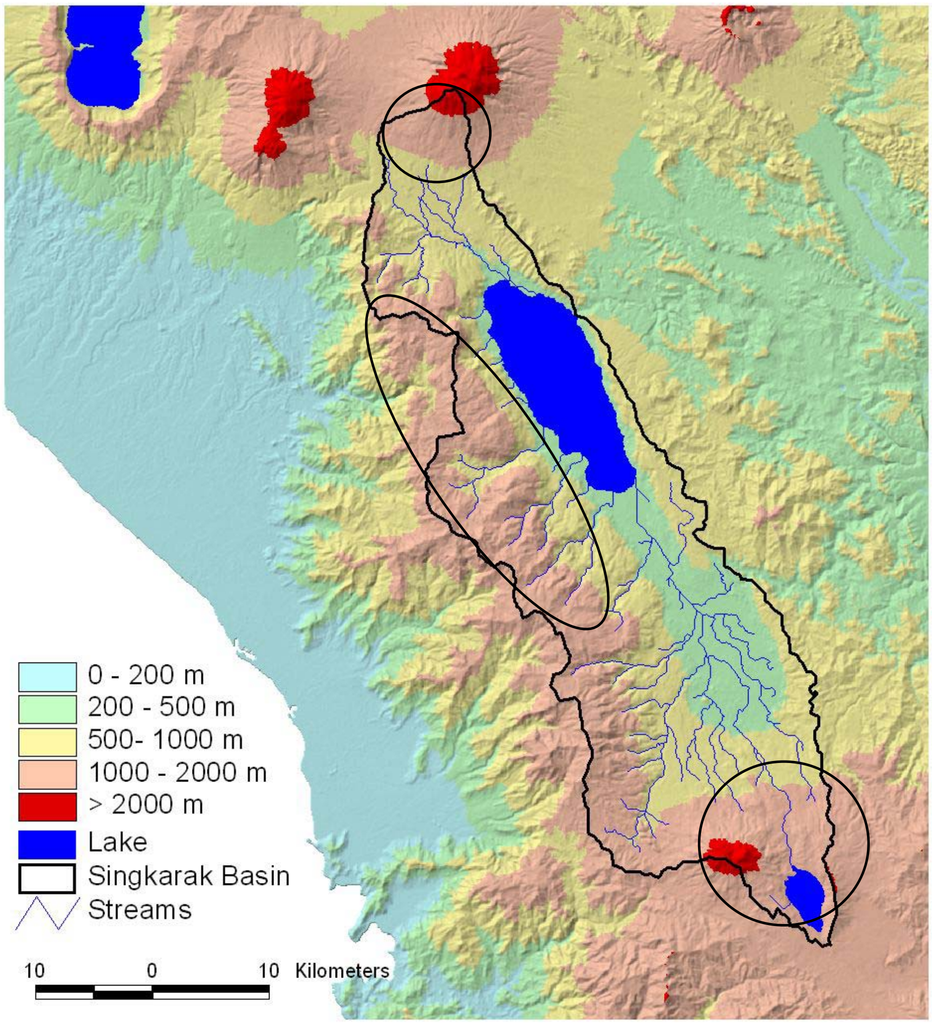

Figure 3.7. Upstream areas in Singkarak Basin

b. *Western upstream*
The western upstream areas have different 'landscape stories' compared to the southern one. Since these areas become the major interest in RUPES work and RHA studies, more detailed description will be explained in the next section.

c. *Northern Upstream*
The northern upstream area starts from Mt Merapi and the vicinity, and is closer in characteristics to the southern one, yet with shorter streams. Batang Gadis and Batang Sumpur are the main streams. Breccia andesite is the major underlying rocks and agricultural areas of ricefields and vegetables are the major land cover.

Around the lake

The upstream area located exactly around Singkarak lake is one that is west of it with short streams directly flowing to the lake. They coincide with 4 *nagari*s (Guguk Malao, Paninggahan, Muara Pingai, Saningbakar) or 3 subcatchments (refer to Appendix 3 & Figure 3.8). The big streams are, among others. : Batang Malalo and Sungai Paninggahan. Agricultural lands (40% of the areas) cover the lower elevation part. Shrubs and grass *(imperata)* cover approximately 15 % of the area, while forest, including pine forest covers nearly 45%. The area of pine forest is estimated to be approximately 15% of the forested area. The non intensive land cover in this area can be partly explained by the physical conditions where very steep slopes of > 30% are quite dominant (approximately 55% of the area) and the major underlying rocks are granite and limestone (45% of the area), especially in Nagari Paninggahan as the biggest *nagari* in this part of the basin.

3.2 Local Ecological Knowledge

3.2.1 General context

The study was carried out in Paningghan village (*nagari)* in West Sumatera province. The village lies in the sub-district (*kecamatan) Junjuang Sirih* of *Solok* district *(Kabupaten)*. *Nagari Paninggahan* is situated in the south of *Singkarak* lake into which *Paninggahan* river flows. In addition to *Nagari Paninggahan* there are six more villages also called *jorong - Subarang, Parumahan, Kotobaru Tambak*, *Gantiang, Kampung Tangah and Gando*. The traditional system of administrative division into j*orong* was reinstated following the reformation in Indonesia in the late 1990s. Each *jorong* is headed by a representative *wali jorong*. *Jorong Koto baru Tambak* and *jorong Gantiang* are not directly connected to Singkarak Lake.

In 1976 the Indonesian government initiated reforestation programs to rehabilitate the degraded lands, including that in *Nagari* land. Most reforested areas were exposed to high fire risk. Community controlled land, lying on hill slopes were planned for agroforests with fruit trees, clove and candle nut or kemiri (*Aleurites molluccana).* Only last year, under the re-greening or afforestation program, community lands were planted with trees with support from APHI (*Assosiasi Pengusaha Hutan Indonesia*) and GNRHL (*Gerakan Nasional Rehabilitasi Hutan dan Lahan Kritis*). Prior to this, there were clove trees and alang-alang (Imperata).

The area is hilly with little flat land for cultivation. This area includes *Nagari* Land, community land. Coffee was cultivated in the past but farmers now do not harvest coffee anymore. Irrigated rice fields (sawah) are towards hill bottom, close to the Singkarak Lake. Coconut trees are abundant in the rice fields as well as in field boundaries.

Table 3.6 .Major land use in Nagari Paninggahan

Local name	Description	Common vegetation
Perbukitan (hills)	Perennial trees on hill slopes; used for reforestation purpose	Pine, clove, coffee, teak, Swetenia, Mahogany, *Sawo*, avocado, *Melinjo*.
Ladang (upland agricultural land)	Arable land on upper slopes mainly for annual crops	chili, onion, soybean, maize
Sawah (lower, usually irrigated, rice fields)	Either rain-fed or irrigated; may be combined with perennial crops; coconut is abundant	Rice, coconut, kapok
Pekarangan (home garden)	Usually attached to the house; vegetables, fruits	Fruits - avocado, clove, sawo, kemiri, banana and other perennials.

Rains in the wet season are more intensive (6-9 mm/hour) while in the dry months; it can be less than 3 mm/hour (Program penyuluhan Pertanian Tahun, 2003).

There are five ethnic groups in Nagari Paninggahan - Guci, Penyalai, Koto, Jambak and Pisang. People, usually of men of 18-40 years in Minangkabau, including Paninggahan, have a tradition of leaving home in search of job (merantau) or study. They usually go to nearby towns and most head towards Java where job opportunities are relatively better.

Farming systems in *Nagari Paninggahan* are oriented towards production of food crop, horticulture, crop industry and fishery. Food crops include rice and maize; horticulture system includes chili, onion, avocado, sawo fruit and *Kemiri*. The main fish for consumption is *Bilih* fish that is considered the original species in *Singkarak* Lake. Other species on the lake are *Sasau* and *Balingka*.

Government regulations on *Paninggahan* are executed by the village government (formal government) while local customary rules are overseen by local village leaders following their traditional Adat systems. Formal government institutions include BPN (*Badan Perencanaan Nagari*) and village government (*Pemerintahan Nagari*). *Karapatan Antar Nagari* or KAN is a traditionally recognised village institution with members as "ninik mamak" as well as intellectual and religious leaders. *Bundo kanduang* is another women group organised for each *Sukus* (ethnic). *Majelis Ulama Nagari* or MUN is primarily for religious purposes in the villages.

3.2.2 Major stakeholder groups

Initial discussions with local people and leaders indicated three broad groups – farmers, government institutions and non-government institutions. The farmer group was then split into men and women groups, hence resulting in four stakeholder groups for exploring their knowledge and perceptions. The male farmers are the primary stakeholder group in the area and the group included heads of farmer groups from each jorong. The fishermen are included in the group. The female farmer group included a head of farmer group in the area. The government group includes heads of each jorong and members of Badan Perencanaan Nagari (BPN). The informal government group includes chiefs of the non-government institutions in Nagari Paninggahan.

Table 3.7. Stakeholder groups in Nagari Paninggahan

Stakeholder	**Male farmers**	**Female farmers**	**Local government**	**Non-government**
Number of people consulted	10	4	5	3
Composition	Jorong Subarang, Parumahan, Gando.	Jorong Gantiang, Koto Baru, Kampuang Tangah.	Head of Jorong, BPN (Badan Perencanaan Nagari)	Bundo Kanduang, Majelis Ulama Nagari, Karapatan Antar Nagari.

3.2.3 Knowledge and perceptions per topic

Trees, forests and water

Amount of water available in the system is influenced by season, soil type, and tree coverage. This seemed to be a general understanding of most people among all stakeholders. The type of trees (pines versus broadleaves) is perceived to have an effect in the evapo-transpiration from leaves with an influence on the total availability of water in soil and water flowing downstream. Overall, the water availability is rather good in Paninggahan area and water becomes slightly scarce only in the dry season. The seasonal influence is the most critical. Ground water sources dry up in the dry season.

- *Availability of water decreases in the dry season*
- *A decrease in ground water availability affects water sources.*

The understanding of the influence of pine on water availability is interesting. In the recent years, pine has been used in extensively in the area in reforestation programs. The general perception in Nagari Paninggahan is that pine trees absorb much water. People in the area perceive that water evaporation from pine needles is rapid (compared to native broadleaves) and this is attributed to the smooth needles and deep roots. On the contrary mahogany and teak are used as example species that do not need much water. The local people claim that soils have 'dried up' after pines were planted in previously forested areas. People in Paninggahan expect that boradleaf species and other fruit trees in reforestation programs can return the land to previous state of natural forest and this will increase water in the springs.

- *Pine trees make soils dry.*
- *If pine trees are replaced by other broadleaves (natural species) the springs will return..*
- *Grasses and crops decrease exposure of land.*
- *Exposed land increases water evaporation and soil erosion.*
- *Trees inside forests help retain water in the soil and prevent soil erosion.*

High evaporation from soil reduces water availability underground. Consequently water availability in the area is affected. Water evaporation from soil is also related to land coverage. In reforestation areas, much land remains exposed increasing evaporation rate. The litter of pine is also considered a fire hazard as the dry needles burn easily. Planting crops inside reforestation area is seen as a positive action as this decreases exposed land thereby decreasing evaporation from soil.

- *Pines absorb a lot of water from soil because they have deep roots.*
- *Pines have needles with smooth surface that allows rapid water evaporation.*
- *Dry needles of pines burn easily when dry.*
- *Exposed land evaporates water easily.*

The soil type also influences water availability under ground. Soils with high lime content are do not hold or stop water permeating through them. So any water from rain enters the soil and reaches ground water. Easily penetrable soil is called Tanah Karang as in Gando district. On the contrary, clayey soil retains as well as stops water moving vertically in the ground.

- *Rain water does not penetrate tanah merah that have high clay content.*
- *Tanah karang have a lot of lime and is easy for water to penetrate.*

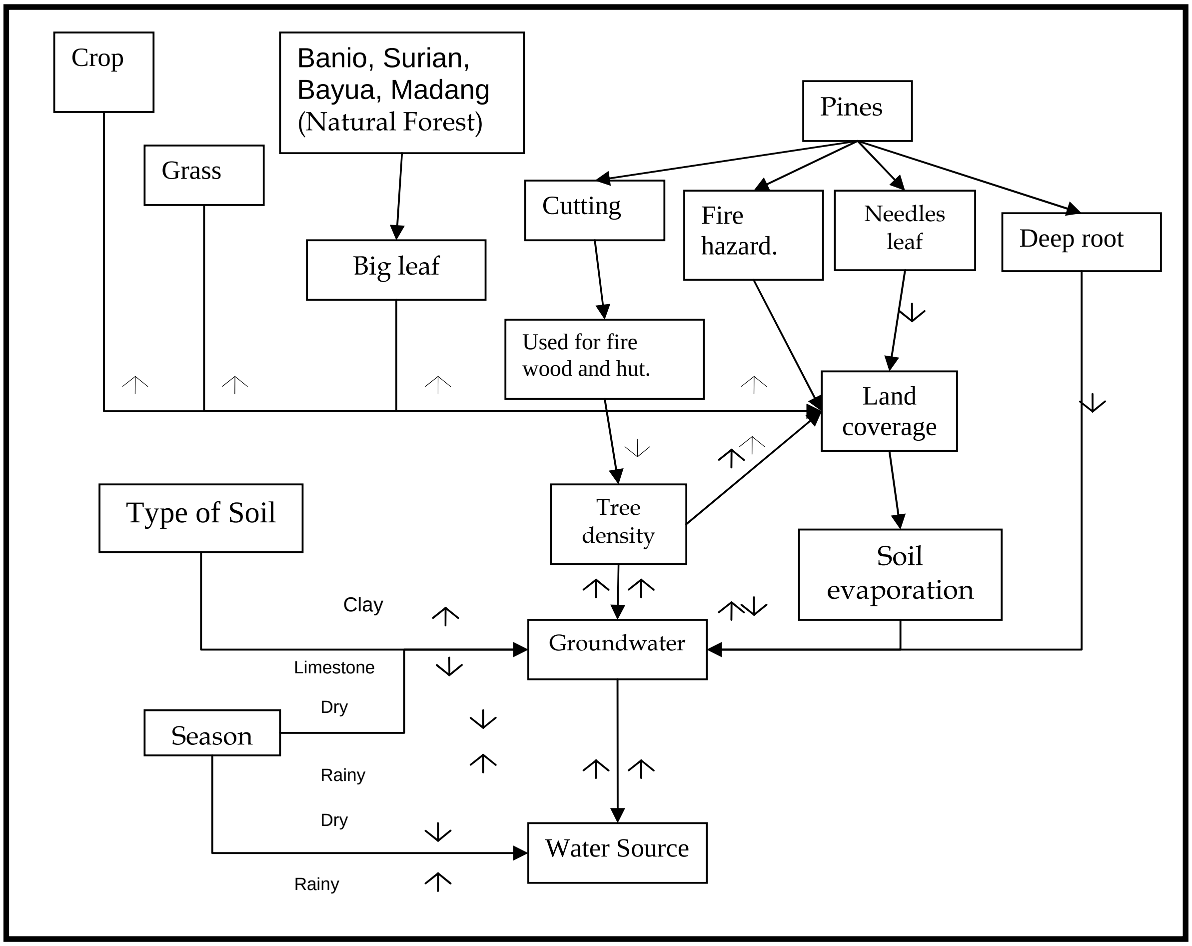

Figure 3.9 Representation of local perception of causal relationship of different factors influencing water availability in Nagari Paninggahan.

Flooding

Singkarak Lake is fed by a number of rivers in the catchment area. Understandably, water level in the lake rises with the increase in input from its feeder rivers. The problem of flooding around the lake has increased since the construction of the dam (PLTA) at the exit point. As the water in the lake rises (often by several meters) over its holding capacity, floods enter the paddy fields around the lake.

- *In the rainy season, increasing water level in Singkarak Lake causes flooding around the lake.*
- *An increase in amount of water in the rivers increases amount of water in the lake.*
- *The reduced flow of water, caused by the PLTA dam, increases flooding around the lake.*

There is no serious flooding problem in the downstream area of Paninggahan. This is attributed to the trees on riparian areas and forests upstream. Increase in water in river is because of heavy rain. Quick flow also causes meandering of the river. River meandering causes erosion if there are no trees in the riparian areas. Sedimentation also occurs that make river shallower. Soil erosion also causes sedimentation in the lake that reduces water holding capacity. Vegetation in the riparian areas is considered to reduce erosion and sedimentation in river and the lake. Around Paninggahan river area beringin, coconut, rumput gajah, sempur and banana are normally retained.

- *Trees along riparian zone and forests of Paninggahan reduce flooding even when there is heavy rain upstream.*
- *Trees in forests help hold water and prevent flooding.*
- *Fast flowing causes river meanders.*
- *Reduced water level in the lake causes fast flow of water in river flow is effect from.*
- *Erosion caused turbidity in river and lake.*
- *Sedimentation from erosion causes lake shallow.*

An increase in water level in lake causes flooding of rice fields along the edge of lake. This can lead to a decrease in rice production. If rice remains submerged under water for a long time its roots will die. Flooding also damages dikes in the field and irrigation channels.

- *Flooding around the lake damages rice fields.*
- *Flooding decreases rice production.*
- *Flooding causes death of roots of rice plants if the plant is submerged under water for prolonged periods.*

Quality of lake water
The rivers flowing into the lake provide most of the water in Lake Singkarak. Hence, water quality of lake is a direct effect of water quality in its feeder rivers.

Water quality of lake is, however, influenced by erosion in the upstream areas. Household and market waste, pesticides and other chemicals often end up in the lake. Heavy erosion causes soil from upstream to be carried in the form of sedimentation resulting in high water turbidity in river water and lake water. Sedimentation also raises the lake floor.

- *Household and market waste, soils and organic material cause high turbidity of lake water.*
- *Waste materials remain in the lake as water is not allowed to exit as PLTA closes the outflow.*

Slope of cultivated land, soil type and land coverage effects erosion. According to the farmers, erosion is not a serious problem in Paninggahan. Erosion takes place only when rain in the upstream area is very heavy. When this happens, the river water is red and the area is flooded. This is also contributed by exposed land upstream that have pine forests. The farmers said that this is a rare occasion (as it happened only once so far). The hills are not so steep and soils are stony; hence erosion does not occur so seriously in Paninggahan (vis-à-vis other villages round the lake). Trees, particularly broadleaved species in the forests play an important role in holding water and the soil and reducing quick water flow and consequent erosion.

- *Heavy rain upstream areas of Paninggahan causes water in the river to become red.*
- *No steep hills reduces erosion problem.*
- *Stony soils allow rain water to permeate easily. This reduces surface flow and erosion.*

A decrease in the quality of lake water has reduced the population of Bilih fish, the indigenous fish in Lake Singkarak. Farmers try to cultivate this fish.

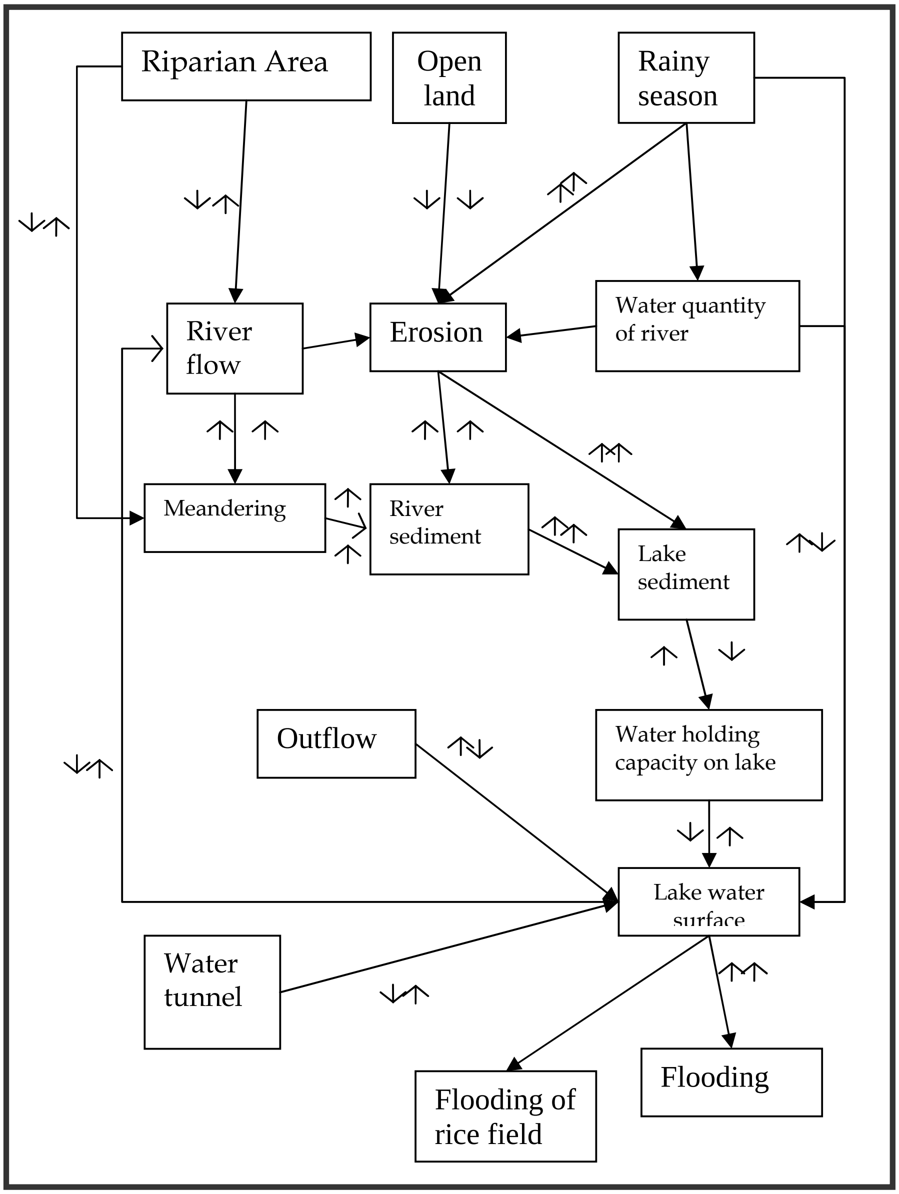

Figure 3.10 Local understanding of causes of flooding in Nagari Paninggahan.

- *Bilih fish like clean and flowing water.*
- *Reduced water quality reduces Bilih fish population.*

3.3 Policymakers and Public Ecological Knowledge (PEK)

The current PEK study was conducted in a matrix of locations within West Sumatera in order to survey the perceptions of differing levels of the government administrative and agency hierarchy, and capture perceptions of people and organizations working the differing physical locations of the river basin (i.e. what could be considered as differing environmental management zones).

In result, during conduct of survey the team visited:

- the regional (South Sumatera region) office of PLN in Bukittinggi;

- West Sumateran provincial-level government and agency informants in Padang;
- district-level, catchment and lake-basin related, government and agency informants in Solok and Kayaro, Solok District, and in Batusangkar, Tanah Datar District;
- municipal-level, urban related, government and agency informants in Solok and Padang Panjang townships (Municipalities);
- district-level and sub-district, downstream related, government and agency informants in Sawahlunto township and at Talawi, within the Sawahlunto Municipality;
- sub-district and nagari-level, catchment and lake-basin related, government and agency informants in Sumani and Paninggahan villages, Solok District;
- public informants, catchment related, in Muarapingai, Saningbakar, Aurduri and Kapuh, villages, Solok District;
- public informants, lake related (fishermen), in Kacang village, Kacang Nagari, Solok District, and Tanjung Mutiara village, Batutebal Nagari, Tanah Datar District; and
- public informant, downstream related, Bukittamasu village, Tanah Datar District

a. Stakeholder groups in land, water and environmental management
The following summary provides detail of PEK survey implementation, and the informants major stakeholders groups contacted having policy, management or livelihood-related concern with respect to land, water and environmental management within the Lake Singkarak basin and immediately downstream.

Provincial and Regional Level

Visits were conducted to the regional (Hydro) Electricity Generating Corporation (PLN – PLTA) , and to five provincial-level government 'stakeholder' agencies (i.e. the planning (BAPPEDA), forestry (BPDAS and Dinas Kehutanan), water (Kimpraswil – PSDA), environment (BAPPEDALDA) and land registration (BPN) agencies) , resulting in interviews with 19 senior managers. Visits were additionally made to field level (Asampulau, Malalo and Ombilin) Hydro-Electricity Generating Corporation (PLN) infrastructure, power plant and offices. Interviews were conducted with 4 senior field and operational staff, respectively, to obtain an on-ground view of PLTA infra-structure and gather information regarding operational procedures.

District Level

The main body of PEK survey conducted at district-level, involved interview with: the Bupati, Solok; with 14 senior technical and managerial staff within seven government agencies[4] of Solok District; with 2 senior staff of Solok Municipality; with 9 senior staff from five government agencies[5] of Tanah Datar District; with 6 senior staff from two agencies[6] of Padang Panjang Municipality; with fishermen's community representatives in two lake-side villages[7]; with 10 community members from four adjacent river sub-basins[8] within Solok district; with 1 local community member (Bukit Tamasu village), 2 senior Kecamatan officials (Talawi township), and 3 senior public works, water and irrigation staff (Sawahlunto Municipality), on the Ombilin river, 6, 25 and 35 km respectively downstream of the PLTA, Ombilin weir.

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[4] i.e. Planning (BAPPEDA), forestry (Dinas Hutbun), agriculture and fisheries (Dinas Pertanian), water and irrigation (Kimpraswil), public health (Dinas Kesehaten), environment and mining (Dinas Pertambangan dan Lingkungan Hidup) agencies, and the domestic water supply company (PDAM).

[5] i.e. Planning (BAPPEDA), forestry (Sub-Dinas Kehutanan), agriculture (Sub-Dinas Tanaman Pangan), fisheries (Sub-Dinas Perikanan) and public works, water and irrigation (Dinas Kimpraswil) agencies.

[6] i.e. The town planning, water and irrigation and solid waste disposal agency (Kimpraswil) and the domestic water supply company (PDAM).

[7] Kacang Nagari, Solok District on southeast lake shore and at Tanjung Mutiara, Batu Tebal Nagari, Tanah Datar District, northeast lake shore.

[8] The Muara Pingai, Kuok, Mandasuluk and Immang Gadang river sub-basins.

Interviews per Stakeholder Group
The matrix of PEK interviews conducted (44 separate interviews), inclusive of 4 days of interviews at provincial-level, is outlined in table 3.7:

Table 3.7 Interviews to identify public/policy ecological knowledge

Groups	***Urban***	***Catchments***	***Lake***	***Downstream***
Provincial		***3 interviews, 3 agencies*** *(planning, environment & forestry)*	***7 interviews, 3 agencies*** *(electricity, planning & environment)*	***2 interviews, 1 agency*** *(electricity)*
Solok	***3 interviews, 3 agencies*** *(drinking water, agriculture & environment)*	***5 interviews, public;*** ***4 interviews, 4 govt. administrators*** *(Bupati, Camat, Wali nagari & Wali Jorong);* ***9 interviews, 7 agencies*** *(water, drinking water, environment, health, forestry, planning & agriculture / fisheries)*	***1 interview, public;*** ***1 interview, fishermen;*** ***4 interviews, 4 govt. administrators*** *(Bupati, Camat, Wali nagari & Wali Jorong);* ***6 interviews, 5 agencies*** *(water, environment, forestry, planning & agriculture / fisheries)*	
Tanah Datar	***3 interviews, 2 agencies*** *(drinking water, & public works)*	***1 interview, public;*** ***1 interview, fishermen;*** ***5 interviews, 4 agencies*** *(planning, water, forestry & public works)*	***1 interview, fishermen;*** ***4 interviews, 5 agencies*** *(planning, fisheries, agriculture & public works)*	***1 interview, public;*** ***3 interviews, 3 agencies*** *(planning, fisheries & agriculture)*
Sawahlunto				***1 interview, 1 govt. administrator*** *(Camat)* ***1 interview, 1 agency*** *(public works / water)*

b. Knowledge and perceptions
Guided by the checklist of issue topics outlined under the 'Stage 4: Stakeholder and Issue Identification' methodology heading above, the primary aim of the PEK survey was to explore the differences in knowledge and perception of differing stakeholder groups concerning landscape, water resource and environmental interactions at the river basin scale.

The secondary aim of the PEK survey was to use this 'local knowledge' to assist in a scoping environmental impact survey of the differing factors influencing water supply, water quality and water demand within the Singkarak lake basin. In view of this, survey results have been separated in a cascading manner: running from upper catchment, to lake, to downstream; and from land use, to rehabilitation projects, to within-lake developments, to PLTA hydro-electric scheme, to other developments. This was done to assist in analysis of the differing impacts, of differing activities, in differing locations, upon water quantity and quality. As such, the structure of results presentation follows a hierarchy of headings as institutional issues, catchment condition and water suply, catchment rehabilitation schemes, lake and fishery condition, PLTA hydro-electric scheme impact, other development impacts and water used pattern.

1. *Institutional Issues*

   An exploration of the existence of any institutional issues which may be affecting the management of water supply or use within the catchment.

   Taking a focus upon the broad topic of 'institutional issues' effecting land, water and environmental management within the Singkarak lake basin, during interview discussion concerning 'institutional coverage' or 'what is the big issue', in eight of the 44 interviews, a small number government agency officials at regional, provincial and district-level.

   National Electricity Corporation (PLN) regional officials, coping with community protest against the Singkarak hydro-electricity power scheme development and the lack of community access to PLN 'water tax' funds, stressed the following points relating to communication and cooperation between regional and local-level stakeholders.

- *The need to counter local community demonstrations against PLN (for security of infrastructure and staff) which have arisen due to this.*
- *The issue that PLN 'water tax' money is not reaching these 'effected' local communities.*
- *The need to develop a program of direct assistance and cooperative effort with lakeside communities – to counter protest and address the lack of provincial / local government effort and funding input.*
- *The need for effective communication with local communities and organizational transparency as the key to local community cooperation and the building of trust.*

   Provincial level Forestry Department catchment management (BPDAS) officials are more concerned with the institutional approach and infrastructure to facilitate river basin-wide catchment and water management.

- *BPDAS is effective if networking is strong, and they may play the role of facilitator.*
- *There needs to be an additional 'think tank' to discuss and decide on which areas should be targeted for tree planting and catchment management in each area.*
- *A previous provincial steering committee to facilitate networking on river basin management (Dewan Dearah Air - Commissi A) was in-effective and failed completely.*
- *The current provincial steering committee (Committee for Integrated Catchment Management) is only orientated to government organizations. It does not allow membership of NGO's or parastatal (BUMN) and private organizations.*
- *A new provincial steering committee is needed ('forum DAS') which includes all stakeholder organizations, to coordinate river basin management at provincial level, act as 'think tank', and hopefully function in the long run as a 'watch dog' for catchment function management.*
- *The current 'Committee' at least facilitates communication between the government organizations at provincial level. Yet no integration of activities.*
- *What is needed is the internalization of catchment management principles into the planning of all member organizations to ensure catchment function conservation and management.*

Provincial Forestry Department spatial and programme planning officials raised their concern with regard to the current process of mapping and verification of Nagari boundaries.

District level agency officials in Solok and Tanah Datar commented broadly on the need for stakeholder coordination and integrated effort to achieve more effective management of the Singkarak lake basin. Solok, Mining and Environmental department respondents were concerned with effort to control of water quality and pollution within the river basin; Solok, Agriculture and Fisheries respondent with overall catchment conservation and management; and Tanah Datar Fisheries respondent with integrated management of the lake and its fishery, in face of differing distinct laws and policies.

- *The big issue within lake basin and district is the water quality and pollution within the Lembang and Sumani river catchments. Each stakeholder in the process needs to take action to reduce the overall impact.*
- *There needs to be a comprehensive approach to catchment management and conservation in the District to achieve effect.*
- *Managing fish stocks and lake condition, with the current situation where there are two Districts manage one lake (with differing rules, regulations and development policies), is difficult.*

In line with his broad institutional planning and management role, the Tanah Datar Planning agency (BAPPEDA) respondent was concerned with the broad challenge of changing stakeholder perceptions regarding land and water management, as well as numerous legal, institutional support and spatial planning issues.

- *We have to change the perception of all stakeholders, government agencies, private business and local communities, regarding land and water management within the district if we are to have any impact to improve the current situation.*
- *The management of lake and water resources has to be supported (coordinated) by provincial and national agencies.*
- *Especially support there will be needed from Provincial level to coordinate the management of the lake between the two Kabupaten.*
- *The issue of land rehabilitation (tree planting), also needs strong support with clear regulations and sanctions from national and provincial levels.*
- *Currently there is a special authority (a steering committee) at provincial level for management of Lake Singkarak. It should operate by issuing laws to assist in water and catchment management. If there is no 'SK Gubernor' (decree from governor) there is no legal solution to most of the current problems.*
- *Especially support will be needed from Provincial level to coordinate the management of the lake between the two districts.*
- *Laws for spatial planning are currently not strong enough to support good catchment management.*

2. *Catchment Condition and Water Supply*

An exploration of catchment function / water supply patterns (both quantity, pattern and quality), with focus upon the upper catchment areas surrounding the lake, and the combined influences of climatic differences, landscape, land use and forest cover.

Review of perceptions of respondents regarding catchment condition and water supply trends within the Singkarak lake basin suggests the basin may be to fall into five zones of differing catchment degradation: the Lembang sub-catchment, Sumani sub-catchment, Barisan range western lake shore and Sumpur sub-catchments, the Aripan and eastern lake shore catchments, and the Tanah Datar district (Mount Merapi) sub-catchments.

In Solok District, three agency respondents (planning, public works and environmental agencies) declared the combined Lembang and Sumani sub-catchments to be the worst in the lake basin with respect to catchment degradation, water supply and water quality (sediment and pollution) problems. Seven agency respondents in Solok (environment, agriculture, municipal agriculture, planning, public works) declared the Lembang catchment to be the most degraded catchment in the district; and one agency (public works Padang Panjang) declared it to be most degraded in the basin total basin.

- *Lembang and Sumani sub-catchments are the most degraded in the district, yielding highest sediment rates (although no measurements taken yet).*
- *From field experience it would appear that the Lembang river has the worst sedimentation rates.*

Six Solok agencies and Padang Panjang agency respondents (as above) considered the primary cause of degradation to be the loss of forest cover in the upper Lembang catchment. Four agencies (planning, public works, forestry / catchment conservation and municipal agriculture) considered the combination of illegal logging, fire and forest clearing for upland agriculture expansion to be the cause of forest loss. The forestry catchment conservation agency remarking that the problem began 15 years ago. Four agency respondents (agriculture, forestry and plantation director, sub-district forest catchment conservation and environmental) considered illegal logging alone (around the slopes of Mount Talang and the upper Lembang) to be the main problem factor. The forest and plantation director outlining that the problem has become much worse in the last 5 years.

- *The need for government (GNRHL program) to rehabilitate the degraded catchments is the major issue within the district.*
- *The primary issue is loss of forest, due to agriculture expansion and illegal logging*
- *Followed by lack of conservation works and erosion prone cropping techniques in agricultural areas.*
- *Followed by water quality degradation and rubbish disposal problem due to settlement and population expansion.*
- *Followed by increasing pollution risk from use of agricultural pesticides*
- *Dry season low flows are leading to water supply shortage for domestic and irrigation use in the Lembang, Aripan and eastern lake shore catchments.*
- *A main current problem within the District continues to be illegal logging.*
- *The Sumani sub-catchment is in better condition, as forest is less damaged. Yet an illegal logging problem does exist.*

The district governor, four Solok agency respondents (agriculture, municipal agriculture, forestry catchment conservation, planning and public works) and Pandang Panjang public works agency all highlighted the flows of the Lembang to be unstable due to above degradation. The same respondents remarking on lower Lembang (at Solok town) having an annual flooding problem due to catchment degradation. Five agencies (agriculture, municipal agriculture, environment, planning and public works) noting the problem to have been made worse by the sedimentation of the lower Lembang river channel. The planning and public works agencies noting that the flooding problem began 20 years ago. One agency (forest catchment conservation) noting the problem primarily to be caused by the high rainfall in the upper catchment combined with degradation, leading to more rapid in-slope and within lembang river flow. One agency (agriculture) also noting the combined catchment size, steepness and rainfall, plus degradation were the problems. Two agencies (planning and public works) considered poor upland agricultural practices (lack of terracing, crops in rows down slope) to be a contributing factor.

- *The major land use problem is that there is too much water in the wet season (in the rivers, causing flooding); and too little water in the dry season (causing a shortage of water for crops and agriculture).*
- *Sediment build-up within the Lembang river near Solok now needs dredging, at it causes flooding. The meandering course of the Lembang near Solok also causes the flooding and requires engineering interventions (a river straightening diversion and levee banks).*
- *The Lembang river flooding more often than the Sumani. This is because the catchment area is bigger than Sumani, and also because the topography is steep.*
- *Additional problem is that the Batang Lembang has a meandering course above Solok. This increases the flooding also. It needs to be straightened to decrease the flooding.*
- *Plus 40% of the areas of degraded catchment should be planted with trees.*
- *From field experience it would appear that the Lembang river has the worst sedimentation rates.*
- *The reason for this is the change in upper catchment land use.*
- *The issues are: a) loss of forest from shifting and upland cultivation; b) illegal logging and forest damage; c) the system of agricultural soil management (no terraces and planting crops in lines down the hill); d) increase in houses and settlements (with rubbish and waste production) and e) increase in pesticide use (on all crops).*

The district governor, four Solok agencies (agriculture, municipal agriculture, forestry catchment conservation sub-district, planning and public works), and Padang Panjang Public works all noting the pronounced dry season low flows within the lower Lembang. Three agencies and Padang Panjang public works attributing this instability to loss of forest in the upper catchment; and one agency (forest catchment conservation sub-district) attributing the low flow to excessive irrigation off take in the mid to lower catchment (claiming the upper lembang flow was still stable even without the forest). Three Solok agencies (planning, public works and agriculture) noting the seasonal low flows to have led to dry season water supply shortages in the lembang and upper lembang sub-catchment respectively.

- *The instability of river flows, flooding in wet season and water shortages in dry season, is the main problem issue with land and water management in the district.*
- *Catchment areas such as Lembang Jaya, Talang and Payung Sekaki are notably degraded catchment areas.*
- *Dry season low flows are leading to water supply shortage for domestic and irrigation use in the Lembang, Aripan and eastern lake shore catchments.*
- *Sedimentation and flooding of the Lembang river near Solok town is an issues*

Two Solok agencies noted the upper Sumani catchment, in comparison to the Lembang, be more stable in dry season flow (forest catchment conservation sub-district agency) and have less floods (agriculture department). Two agency respondents (forest and plantation director and forest catchment conservation), noted in turn the better condition of the upper Sumani because of the greater area of upper catchment undisturbed forest cover, lower frequency of illegal logging and less road access within the Barisan range forest reserve.

- *The upper Sumani sub-catchment is in better condition and less damaged. Yet there is still illegal logging and has been for 60 years.*

The forest catchment conservation agency noted however that a low level of illegal logging had been occurring for 60 years in the Sumani sub-catchment. Public respondents, on the Kuok and Immanggadang tributaries, confirmed the existence of unstable flows, wet season floods and high sediment loads and dry season low flows in their lower Sumani basin sub-catchments (flowing from volcanic Barisan range uplands). The cause of these catchment function problems they attributed to upper catchment forest cover loss, due to expansion of upland agriculture and plantations into the forest areas. Respondents on the Kuok stating this to have begun since 1945 (60 years ago). Respondents on the Immangadang noted the catchment degradation to have begun in the last 25 to 20 years.

In comparison to the above Sumani sub-catchments from the Barisan range, the western lake shore catchments and Sumpur catchment, draining from well-forested limestone and granite uplands show more stable catchment flow. A public respondent on the Muarapingai river noting the river to be relatively stable (reasonable dry season flow, slight floods and some sediment in wet season), remarking the upper catchment still to be well forested, due to the lack of an access road. The Wali Nagari of Paninggahan remarked on the Paninggahan and Sumpur rivers as being the only stable rivers remaining in the lake basin, with dry season flow remaining good, due to upper catchments remaining well forested (again due to lack of road access to upper catchments).

- *Only two rivers remain in the lake basin with stable flow (i.e. less flood peaks in summer, yet with reasonable dry season flow) – the Paninggahan and Sumpur rivers.*

Within Tanah Datar district two agency respondents (public works / irrigation and Padang Panjang, public works) and fishermen of Tanjung Mutiara, all remarked on the Sumpur river to retain more stable dry season flows and lower wet season sediment levels than other rivers in District, attributable to its good upper catchment forest cover. Padang Panjang public works respondent noting the western lake shore catchments from the Barisan range in general to have suffered the least decrease in dry season flows over 20 to 30 years due to their good forest cover. Tanar Datar forest sub-agency and public works respondents in turn noting that the Barisan range catchment (including Sumpur) had decreased little in dry season flow over the years, due to impact of illegal logging and upper catchment forest disturbance. Water agency, Padang Panjang respondents noting alternatively, that the smaller limestone sub-catchments in the Barisan range were more unstable than other catchments drying out rapidly after rain and less flow in dry season, than catchment off the volcanic uplands, even though they were well forested.

- *Overall discharge of streams flowing from all sub-catchment hills in the lake basin have reduced over time (over a 30 to 40 year career observation period).*
- *Limestone catchments in the Bukit Barisan range show a greater instability of flow (dry out in dry season and after rainfall) – even though forest cover is still good*
- *Water quality from springs in the limestone catchments is also not good – higher sediment levels due to soil washing into sink-holes.*

- *The government agencies are active in tree planting and catchment re-greening schemes, yet the local communities remain equally active in illegal logging and timber harvesting (i.e. the overall impact of the effort is low).*
- *Sumpur river still has good flow even during the dry season. This is because there is still forest in the upper catchment.*

Concerning Tanah Datar district sub-catchments off the slopes of Mount Merapi, two agencies from Padang Panjang (water supply and public works) and three agencies from Tanah Datar (planning, forestry and public works) remarked on a long term trend in decrease[9] of dry season water discharge from the springs that feed the sub-catchments off Mount Merapi. This recorded over a 90 year period of record as stated by PDAM, Padang Panjang; and over 18 years observation by public works Tanah Datar. One agency (public works, Tanah Datar) attributing the decrease primarily due to past illegal logging (by community and the military) and forest disturbance. Two agencies (water supply Padang Panjang and planning Tanah Datar) attributing the decrease to the loss of forest cover on communal forest lands (70% to 80% loss), due to expansion of upland agriculture, plantations and vegetables. Three agencies (Padang Panjang water supply and public works, and Tanah Datar planning) confirming forest cover within the forest reserve (on upper slopes) of Mount Merapi to remain in good condition.

Two Tanah Datar agencies (public works and planning) adding that the degradation of communal forest had led to increased landslides, erosion and sedimentation into sub-catchment rivers and lake arising largely from the communal forest lands. Three Tanah Datar agencies (planning, forestry and public works / water) and fishermen in Tanjung Mutiara noting the growing trend of irrigation off take (and water supply shortage) of mid to lower slope irrigated rice fields throughout the district, resulting in little to no dry season flows in sub-catchment rivers off the slopes of Mount Merapi into the lake, or down the Selo and Bengkawas sub-catchments into the Ombilin river. The Tanah Datar planning agency respondent being particularly concerned that this growing (or constant) community use of water for irrigated rice, PLTA continued use of water from the lake and the decreasing supply of water from upper catchment springs and degraded forests, would eventually lead to the Tanah Datar district sub-catchments having no water left in 20 years.

- *A major water supply spring on Mount Merapi has decreased its dry season yield over a 90 years period of record. Spring discharge was always lower in dry season due to lower rainfall, yet is now additionally affected by upper catchment land use change.*
- *Overall upper catchment forest disturbance over the last 18 years in the district has led to a decrease in catchment water supply to support irrigation areas.*
- *Irrigated rice on the upper slopes of catchments and above the lake is using up the catchment supply and water input to catchment rivers and the lake is decreasing.*
- *Community forest areas (Tanah Ulayat) are however very disturbed, only 20% forest cover left. and a source of erosion and stream sediment input.*
- *PLTA is using a large amount of water, yet the community needs more water also (there is a potential conflict growing)*

Lastly, a total of seven agency respondents (provincial environmental; Solok planning, public works, water supply and sub-district forestry catchment conservation; Tanah Datar forestry; and Padang Panjang public works), and one public respondent (resident Paninggahan), have remarked on either the eastern lake shore or Aripan sub-catchments, as being the driest, most unstable and water deficient catchments within the lake basin. Padang Panjang public works agency, remarking the eastern lake shore zone to be the driest and most unstable in catchment flow in the lake basin. Five agencies (Solok public works, forestry catchment conservation, planning and water supply) noting the Aripan and eastern lake shore catchments in Solok to be the driest most unstable catchments. Three agencies (provincial environmental, and Solok planning and public works) noting the Simawang and Ombilin areas in Tanah Datar to be particular water deficit areas. Two agencies (Padang Panjang, public works and Tanah Datar forestry) noting the Rambatan area in Tanah Datar to be the most degraded area in the district need of rehabilitation. The Solok, forestry catchment conservation sub-district respondent similarly noting the eastern lake shore sub-catchments to be the most degraded areas in the Solok district. No agencies giving any detail as to the cause or pattern of degradation or instability, other than the climate being drier.

- *The Aripan catchment in the east is driest and water supply least stable (due to climate).*

3. *Catchment Rehabilitation Schemes:*
   An exploration of efforts towards rehabilitation of degraded upper catchment lands, and perceptions of the impact of this activity.

   The majority of government administrative and agency officials remarked positively about the current programmes of catchment rehabilitation effort (GNRHL, Special Funds Allocation or PLTA compensation agreement planting programmes) (i.e. Wali Nagari Paningahan, Camats Talawi and Sijungjungsiri; provincial catchment conservation agency; Solok district, plantation and forestry, agriculture and fisheries, planning and public works, and water supply agencies; municipal water supply agency Padang Panjang and municipal agriculture agency, Solok). These programmes utilizing a government selected mix of timber tree species and fruit tree species within forest reserve and communal forest (tanah ulayat) areas.

- *Forestry Department, GNRHL (Gerakan nasional rehabilitasi hutan dan lahan) programme planted 50ha in Subarang in 2002. Now plans under 2003 programme to plant 50 ha Subarang and 15 ha Kota Baru / Tambak, again with a mix of fruit (cengkeh, coklat, petai, alpokat, durian) and timber (mahoni) tree species.*
- *A Master Plan for RKL (rehabilitation of critical land) already exists (the 1995 document).Plus there is an SK Gubernor for a 15 year RLKT plan. This includes a land use plan with areas which require to be permanently vegetated.*
- *Now the GNRHL scheme plans to cover 52,000 ha within Solok District (under a 10 year plan).*
- *Forest Department also has a physical works programme under GNRHL for erosion control. 6 units of check dams; 16 units of gully plugs; 32 infiltration structures; and 10 unit of other small dams have been installed.*
- *They began with 20ha of forest rehabilitation on the slopes of Mount Merapi above Pandang Panjang. They planted improved species (bibit ungulan) such as: jati super, surian, mahoni, alpokat, petai, durian and kopi.*

Of the agencies as interviewed, most held the perception that these planting schemes would have a positive impact on rehabilitating the degraded catchment lands, and in conserving the lake-basin water resources. Three agencies (Solok, planning, public works and plantation and forestry) admitted that the major GNRHL programme had just started and that it was too early for evidence of positive impact on catchment function. Two agencies (provincial, BPDAS forestry, and Solok, plantation and forestry), highlighted that there were also difficulties in implementation with remarks 'that local communities are not stable on their decisions on tree planting areas', 'there is still a problem with land status with local communities' and 'socialization of the programme is not effective yet'.

- *The programme is not successful yet in the field. There is a problem with 'land status' with the local communities. The socialization programme has not effective yet.*

Three agency respondents (Tanah Datar, planning and forestry sub-agencies; and Padang Panjang, PDAM) however held the opinion that current rehabilitation programmes were not as yet effective, with general comment 'that as fast as the government plants trees on communal forest lands, the community is intent on cutting them down'.

Regarding past rehabilitation programmes, only one respondent remarked in detail and positively concerning the activities of the previous GTZ ProLK project (Plantation and Forestry agency, Solok). Noting the positive impact that this largely extension orientated programme had had in markedly reducing the incidence of community burning activities within alang-alang grasslands on forest edges around the lake. One government administrator (Camat) and nagari staff of Panniggahan confirming that there had now been a marked reduction in alang-alang and forest burning as compared to the past.

- *The main focus of the ProLK project was extension and training. For agriculture, agro-processing, fish catch processing (smoking bilih fish), fish ponds (Nila production) and making of handicrafts.*
- *The idea was to raise the community income from changes in existing livelihood practices, so as to take the pressure off the use of the forest resources in the upper catchments.*
- *Now since the ProLK project, after intensive efforts with the communities regarding extension and education on the subject of burning and catchment damage, there is hardly any burning practiced today. Maybe only once a year in a few places.*
- *There was a focus of the ProLK activities upon 2 to 3 Nagari so as to make impact. The main areas of focus were the Paninggahan, Maurapingai and Saningbakar areas in Solok. Plus Simawang and Ombilin areas in Tanah Datar.*
- *There was a focus upon supply of multi-purpose tree seedlings for planting in Tanah Ulayat, plus elephant grass and handicraft production programmes.*
- *There also was a programme for cattle feed by introducing the improved elephant grass (rumput gajah) species.*

Lastly, two respondents remarked positively (Camat and Wali Nagari Paninggahan) concerning the past 1976-78 planting programme of pine tree species within the alang-alang grasslands and degraded areas around the lake. These species were chosen not because they were ideal, it was because the planting material was available and they established easily in the open grasslands. Three respondents however remarked negatively, concerning the pine species. One Paniggahan public respondent noted how a local spring had dried-up after these pines were planted in the traditional alang-alang grassland grazing areas. A Wali Jorong of the Paninggahan similarly remarked on the negative impact on pines on the catchment, as they use much more water than broad-leaf trees. Plus they are a fire risk due to inflammable pine needles and have now largely disappeared (as they were burnt). Lastly, an agency respondent in Padang Panjang (public works and irrigation), remarked similarly that the past planting of pines was a waste of rehabilitation effort, as they were a fire risk which eventually got burnt and the land returned again to alang-alang or agriculture as it had been before.

4. *Lake and Fishery Condition:*
An exploration of current lake fishery condition (especially the endemic Bilih fish stocks), and existence of impacting developments, within-catchment or within-lake, which impact upon lake water quality and quantity.

Regarding the changes in the lake condition, virtually all agency and lake-basin public respondents provincially, within Solok and Tanah Datar districts and in Padang Panjang township, including PLN (the developers), responded to the questions with regard to lake conditions by highlighting the major impact the PLTA development had has in changing the natural lake-level fluctuations (further details of impact discussed in section below).
Virtually all agency and lake-basin public respondents provincially, within Solok and Tanah Datar districts and in Padang Panjang township, including PLN (the developers), who responded to the questions with regard to PLTA lake-basin impact highlighted the major impact to be that on changing the natural lake-level fluctuations, and the resulting impact on lake-side communities.

Five agency respondents (PLN, provincial and Solok district environment agencies, Solok planning and public works) remarked that there was no measured evidence yet of lake water quality change. Four agency respondents (Solok governor and environmental agency, and Tanah Datar planning and fisheries agencies), and three public respondents (Kacang and Tajung Mutiara fishermen, and Panninggahan resident), had noted a decrease in lake water quality due to catchment pollution impact and were concerned as to how to combat the change. The increased build-up of catchment rubbish in the lake was also remarked on by one government administrator and three agencies (Solok governor, environmental and forest and plantation agency and Tanah Datar planning agency), and one public respondent (Tanjung Mutiara fishermen) (with perceptions of cause discussed in section below).

- *Water quality monitoring is conducted in the lake by PLTA as part of their AMDAL agreement. Data comes regularly, yet it is not checked for its reliability with independent monitoring.*
- *Bappedalda, TkI. is in charge of continuous lake water quality monitoring since 2002. There has been no mention of record of change in lake water quality levels as of yet*
- *The fish population (Ikan Bilih) has reduced. One of the reasons for this is the rubbish and waste now polluting the lake.*
- *There is a problem with fish in the lake. Before there were many, now there are very few.*

One public respondent (Kacang, fisherman) was specifically concerned with the impact of catchment pesticides and fertilizers upon the lake and fish. Three agency respondents (Forest and Plantations, Solok; and Fisheries and Planning in Tanah Datar), and the two lake-side fishermen respondents, specifically commented on the increased sedimentation impact on the lake due to catchment erosion. Two agency respondents (provincial environmental agency and fisheries, Solok) remarked on the potential water quality (eutrophication) risk of too many 'tambak' intensive fish production units. Yet, noted that lake Singkarak had few tambak at present. Two agencies (public work and fisheries, Solok) also commented on the present and future increasing risk of lake-edge degradation and pollution impact on lake caused by current trends in lake-edge settlement and tourism development.

- *The lake water is now becoming dirty.*

- *The reason is the mud entering the lake, plus the wastes which are being disposed into the Batang Lembang (by Solok town) which are entering the lake.*
- *The poison (pesticide and fertiliser) from rice fields coming into the lake is also a pollution problem.*
- *An upper limit of 15% area of the lake has been set for 'kerambak' fish production to safeguard the lake water quality. Currently only a few kerambak have been established (approx. 0.5% area. They are aware that too many kerambak may cause lake water problems as at Lake Maninjau.*
- *The fish population (Ikan Bilih) has reduced. One of the reasons for this is the rubbish and waste now polluting the lake.*
- *Ikan Bilik need clean water to lay eggs and nurse young. Before around the lake there was clean water and sandy areas, now it is more muddy.*
- *Fish 'tambak' (feeding / production enclosures) to date are few in Lake Singkarak. Not like in Lake Maninjau, where excessive numbers of tambak have caused eutrophication and fish kills.*

Concerning the Bilih fish stocks, government administrators (i.e. Wali Nagari), agency (i.e. Solok and Tanah Datar fisheries, provincial and district environment agencies, and public works Padang Panjang) and fishermen respondents (Kacang and Tanjung Mutiara) highlighted that the Bilih fish numbers had collapsed in recent years. Only the Solok and Tanah Datar fisheries agencies and fishermen respondents (Kacang and Tanjung Mutiara) highlighted as well that the fishing community economy and fishermen number had collapsed also.

Three agencies (provincial environmental agency, and the planning and fisheries agencies in Tanah Datar) and fishermen in Tanah Datar, remarked on the cause behind the decline as being draw-down of lake levels having an impact on the lake water quality (lake bed landslides, and waves stirring-up mud) and Bilik fish breeding habitat, breeding cycle and population numbers. The fisherman in Kacang attributed the decline mainly to pollution and water quality change and loss of fish down the PLTA intake tunnel.

Alternatively, three government administrators (Wali Jorong, Wali Nagari and Camat of Paninggahan), the Fisheries agencies of Solok and Tanah Datar, and fishermen of Kacang and Tanjung Mutiara, attributed the decline in part, or in the main, to the local community use of destructive fishing methods (bombs, poison, electricity, fine mesh nets, specialized fishing gear in breeding estuaries). Two respondents, the Fishery agency, Tanah Datar and fisherman, Kacang also outlining the destructive impact of the rapid increase of fishermen numbers (by 75-80%) on the lake after the 1997-98 economic crisis, and the fact that these new and inexperienced fishermen, in effort to make fast income, introduced the use of most of the new destructive fishing techniques to the lake.

- *The Ikan Bilih population is decreasing due to the impact of fishing techniques. Use of electricity, bombs and fish nets with too small mesh.*
- *Poison and electricity (as well as bomb fishing) have also been mentioned as used in the lake outside of the Paninggahan river fish reserve*
- *Pukat mesh is now 3/4", it would be better to be 1". Small mesh is catching even the small / young Ikan Bilih.*
- *Fishermen however still need socialization, as fishing problems continue to persist. Fishermen are still using 'bombs' (blast-fishing), electricity and poison to catch fish. Plus fishing gear such as jala and tangup.*
- *Combined with the PLTA impact, from 1997 onwards there has been an impact upon the fish population of an increasing number of fishermen on the lake.*

- *The national economic crisis around this period and 1998, meant that many local residents who were on 'merantau' (migration) to the cities, lost there jobs and had to return to their lakeside villages. The fishing business was one of the only activities they could begin to survive on which did not need a big investment.*
- *The total number of fishermen on the lake in this period went up approximately 80%.*
- *It was these returned 'new fishermen' who began the trend in destructive fishing techniques within the lake. Using blast-fishing (bombs), electricity and poison ('potass' and traditional root poisons 'akar tuba') to make a quick and easy income from fishing.*

5. *PLTA Hydro-Electric Scheme Impact:*
   An exploration of the specific impacts of the Singkarak PLTA hydro-electricity development upon lake condition, fisheries and downstream.
   Virtually all agency and lake-basin public respondents provincially, within Solok and Tanah Datar districts and in Padang Panjang township, including PLN (the developers), who responded to the questions with regard to PLTA lake-basin impact highlighted the major impact to be that on changing the natural lake-level fluctuations, and the resulting impact on lake-side communities.

   Most respondents noted that PLTA lake level rises had induced flooding problems around the lake (for settlements, rice fields and fish ponds). A minority of the respondents, the provincial environmental agency, and the planning and fisheries agencies and public (fishermen) in Tanah Datar, remarked on the draw-down of lake levels having an impact on the lake water quality (lake bed landslides, and waves stirring-up mud) and Bilik fish breeding habitat, breeding cycle and population numbers.

- *After PLTA the water level has risen too high and damaged rice fields and fish ponds. Now there is a scheme for compensation if this happens.*
- *During the rainy season the lake now rises and has flooded the rice fields.*
- *During the dry season it now goes down 2 to 3m lower than before.*
- *Before the PLTA the lake level fluctuation was not as much as 1m.*

Five agency respondents (PLN, provincial and Solok district environment agencies, Solok planning and public works) remarked that there was no measured evidence yet of lake water quality change. Four agency respondents (Solok governor and environmental agency, and Tanah Datar planning and fisheries agencies), and three public respondents (Kacang and Tajung Mutiara fishermen, and Panninggahan resident), had noted a decrease in lake water quality due to catchment pollution impact. One agency (planning, Tanah Datar) and all three public respondents (fishermen and resident) blamed this quality change upon the PLTA development, due to change and obstruction of the natural lake 'flushing' currents caused by the Ombilin weir.

The increased build-up of catchment rubbish in the lake was remarked on by one government administrator and three agencies (Solok governor, environmental and forest and plantation agency and Tanah Datar planning agency), and one public respondent (Tanjung Mutiara fishermen). One agency (planning, Tanah Datar) and the public respondents (fishermen Tanjung Mutiara) blamed this quality change directly upon the PLTA development, due to the obstruction of the natural lake 'flushing' currents caused by the Ombilin weir.

Regarding the impact of the PLTA scheme upon the fish populations of the lake the three agency respondents (provincial environmental agency and fisheries agencies of Tanah Datar and Solok) noted that the PLTA development was definitely one of the causal factors (due to lake level, water quality changes and impact on Bilih breeding cycle) in the collapse of the Bilih fish population and fishery. The Solok district governor and environmental agency noted that lake water change due to catchment pollution was impacting upon the fish populations (yet no mention of PLTA). The two public (fishermen) respondents were convinced that the PLTA development was the major cause of the fish population collapse (due to lake level, water quality changes and impact on Bilih breeding cycle), and one agency respondent (public works, Padang Panjang) supposed that PLTA may be the cause of fish population decrease (fish going down the intake tunnel).

Concerning, downstream impacts of the PLTA development there was alternatively a diversity of opinion. The developer PLN at regional and field levels provided information to suggest that there were had in fact downstream impacts (with regard to flood damage after Ombilin gate opening, impact on water-wheel irrigation and need for maintenance of sanitary flows) – yet they now had projects in operation with the community and or systems in place to mitigate these impacts.

Three agency respondents from Tanah Datar (planning, public work / irrigation and agriculture), and the Camat at Talawi (25 km downstream from Ombilin weir) remarked that there was no evidence to date of any negative impacts of the PLTA development downstream (flooding, water-wheel irrigation impacts, other water usage or river fisheries).

One agency (fisheries Tanah Datar) was of the opinion that there had definitely been a negative impact on the downstream Ombilin (disruption of lake and river fish migration routes and breeding cycles, loss of a shell-fish fishery and fishermen livelihoods, and reported loss of 4,000 ha of irrigated rice). A public respondent (Bukittamasu) 6 km downstream from the Ombilin weir, confirmed the negative impact on fish migration and local river fishery, and the negative impact of PLTA induced flooding. Yet, remarked that there was no issue as he could see with regard to a shell-fish fishery, nor with irrigated rice (as all in his area is above the river and supplied from tributary streams). Lastly, the agency respondent from Sawahlunto (public works and irrigation agency), confirmed that there was no negative impact of the PLTA development, in the Sawahlunto area (35km downstream from Ombilin), or anywhere downstream, due to flooding, upon irrigated rice (as all rice was also upslope, away from the river, and supplied by tributary streams), or other water use patterns. There was however a negative impact in 1998-99 upon quite a large number traditional water wheel farmers around the Talawi area due to reduced river flow. These farmers were compensated once and have received no further assistance.

6. *Other Developmental Impacts:*
An exploration of the existence of any other developments, within-catchment or within-lake, which might impact upon catchment function and water quality.

Government administrator and agency respondents confirmed that there were no planned or current large plantation development schemes (forest industrial plantations or other), no significant mining projects (except for small scale quarrying activities), and no major industries with polluting potential (except for limited small scale industry in Solok) within the lake basin.

Within Solok District three agency respondents in Solok did mention interest of cement mining companies to exploit the lake-basin limestone outcrops, two agencies

(Planning and Public Works) were not concerned as to its potential impact, one agency (environmental agency), was convinced the development would impact negatively on local water supply. Local public respondents and Nagari administrators in Panningahan were additionally concerned with the negative impact of a local quarrying activity on roads and potentially catchment water supplies. Three agencies in Solok also mentioned the new Kayuaro township development within the upper Sumani sub-catchment, two agencies were confident it would make no negative catchment impact (Planning and Public Works), one agency respondent (Forest and Plantations) was concerned that it would make a long run degrading impact on the surrounding forest and catchment.

Alternatively, many government administrator, agency and lake-basin public respondents in both Solok and Tanah Datar districts were concerned as to the current negative impact of rubbish disposal and domestic pollution upon of the two major towns (Solok and Padang Panjang) and from minor settlements, upon the major rivers (Sumpur, Lembang and Sumani) and upon the receiving lake. Within Tanah Datar, one agency (Planning) suggesting on a district-wide basis there was much to be done to control the current problem of rubbish, and one agency (Public Works, Padang Panjang) suggesting the problem of rubbish in Padang Panjang township was now under control. Within Solok, similarly, one agency (Environmental agency) suggested that on district-wide and within Solok basis there was still much investment needed to control the pollution and rubbish problems, and one agency (Agriculture, Solok township) suggested that problem of rubbish management in Solok was now under good control.

Two Solok respondents, a public respondent (fishermen from the lake), and an agency respondent (Environmental agency) were additionally concerned with the use of agricultural pesticides and the respective impact upon the lake and fisheries and catchment water quality and food.

7. *Water Use Patterns*

An exploration of the lake and river basin water use and water demand patterns, the balance of water supply versus water demand and existence of water quality related problems with water use.

Lastly the concept of the inventory of perception on 'water use' was intended to explore if in fact the above catchment management, lake condition, PLTA and other development issues, as affecting primarily water supply and water quality, had in fact impacted on the lake-basin water users. Within the RHA framework, this sub-survey explore respondents perceptions as to the fundamental question 'Who is affected by the water use problems and how bad is it?' with respect to the water demand side of the lake-basin management equation.

The results of the 'water use' survey revealed within-lake basin respondents to be generally of the opinion that domestic drinking water supplies for major towns and settlements within the lake basin were still adequate. Of the major towns Solok, Padang Panjang and Batu Sankar, agency respondents confirm the latter is supplied by sources outside the basin, Padang Panjang has ample water supply, despite one spring showing decrease of dry season discharge, Solok has ample supply, despite it sometimes being dirty when Sumani river waters are used. Only, the east lake shore and Aripan sub-catchment communities were noted to be short of drinking and irrigation water by many agency respondents in both districts and one public respondent. The one agency and one public respondent from the east lake shore confirmed the irrigation water shortage, however suggested there was no drinking water shortage. Public respondents in the south western lake basin, alternatively reported no problem with domestic water supply, just that they could not drink water from the rivers as they had done in the past (due to dirty water from catchment).

Regarding irrigation water shortage, various agency respondents from Tanah Datar signalled an current or up-coming problem in the northern-end of the lake basin with respect to shortage of irrigation water supply versus demand. The planning agency respondent considering the growing problem to be most serious. In Solok district, one government administrator (the Bupati) and two agency respondents (BAPPEDA signalled a current dry season water shortage in the district and Lembang sub-catchment respectively. Other agency officials suggested no shortage in the main irrigation scheme, only in the upper Lembang catchment.

Downstream Ombilin river respondents revealed that there was generally no problem of water use from the Ombilin. Downstream irrigated agriculture, in the main, did not use the Ombilin waters. The PLTU power station and the few water-wheels, small-pumped irrigation schemes, drinking water schemes which did use the Ombilin waters, did not at present report any shortage. Virtually all respondents, from government administrators, to Tanah Datar agencies, to public held this view. Only two agency respondents one in Sawahlunto (irrigation agency) and Tanah Datar (fisheries agency) had the perception that there were downstream water supply problems for water-wheel irrigation farmers in 1998-99 after the development of the PLTA scheme.

3.4 Modellers' Ecological Knowledge and GenRiver results

3.4.1 Modifications of model structure

In developing the application for Lake Singkarak a number of additions to the model structure were needed, captured in the version 1.1 of the model.

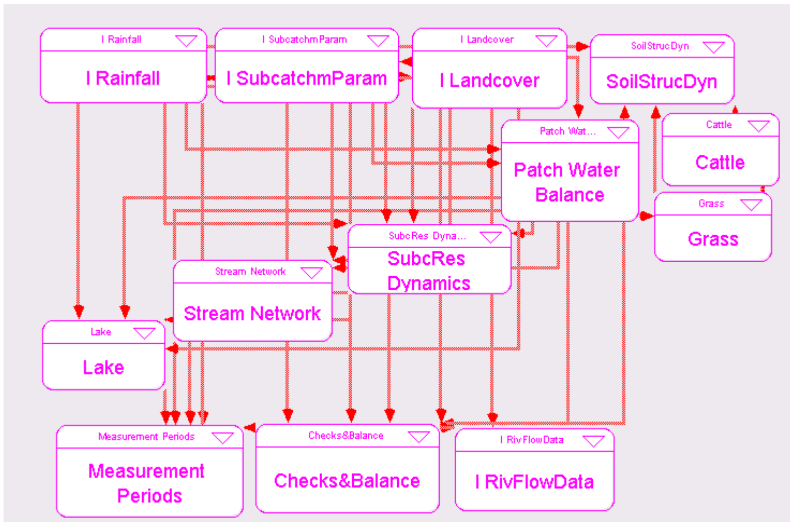


Figure 3.11. Sector structure of GenRiver 1.1 as it was developed for the Singkarak application: the upper sectors handle parameter input, the sectors on the main diagonal describe the flow from patch-level water balance via the stream network to the lake, while the bottom row indicates output converters, checks and balances

3.4.2 Parameterization

Step 1: identifying subcatchments

Table 3.8. Model parametrization of subcatchments with their area, distance to the lake and to the various 'measuring points'

Sub-catch-ment	Area fraction	Area (km2)	Distance to the lake (km)	Sumani outflow	Aripan outflow	Mpingai outflow	Paning-gahan outflow	Perta-hunan outflow	Sumpur outflow
A	0.14	159.1	39.0	34.2	0	0	0	0	0
B	0.088	99.4	33.0	28.7	0	0	0	0	0
C	0.123	139.2	33.0	28.3	0	0	0	0	0
D	0.108	122.5	15.0	5	0	0	0	0	0
E	0.031	34.7	0.7	0	0.7	0	0	0	0
F	0.049	55.2	11.7	11.7	0	0	0	0	0
G	0.053	60	8.0	0	0	8	0	0	0
H	0.106	119.9	10.2	0	0	0	10.2	0	0
I	0.048	54.1	2.6	0	0	0	0	2.6	0
J	0.04	45.2	18.9	0	0	0	0	0	11.2
K	0.087	98.6	15.2	0	0	0	0	0	7.5
L	0.031	34.7	6.9	0	0	0	0	0	6.9
M	0.099	112	0.0	0	0	0	0	0	0
Total		1135							

By overlaying these subcatchments on the soil map, the following proportions of soils were assigned (Table 3.9).

Table 3.9. Distribution of soil types per subcatchment as derived from overlay of subcatchment grid and 1:250,000 soil map in Figure 3.2

Sub-catch-ment	Alfi-sols	Andis ols	Aridi sols	Enti sols	Incep tisols	Molli sols	Oxi-sols	Spodo-sols	Ulti-sols	Verti sols
A	0	0	0	0	1.00	0	0	0	0.00	0
B	0	0	0	0	0.50	0	0	0	0.50	0
C	0	0	0	0	0.50	0	0	0	0.50	0
D	0	0	0	0	0.50	0	0	0	0.50	0
E	0	0	0	0	1.00	0	0	0	0.00	0
F	0	0	0	0	0.50	0	0	0	0.50	0
G	0.25	0	0	0	0.50	0	0	0	0.25	0
H	0.25	0	0	0	0.50	0	0	0	0.25	0
I	0.05	0	0	0	0.75	0	0	0	0.20	0
J	0.25	0	0	0.25	0.50	0	0	0	0.00	0
K	0	0	0	0	1.00	0	0	0	0.00	0
L	0	0	0	0.25	0.50	0	0	0	0.25	0
M	0	0	0	0	0	0	0	0	0.00	0
Time independent soil depth, cm	147	171	110	170	170	165	320	143	180	198
Topsoil depth, cm	25	25	25	25	25	25	25	25	25	25

Table 3.10 Assumed values for other parameters; columns 2-4 are derived from the soil types, and the BD/BDref ratio that is derived from land use types per subcatchment

	Topsoil BD/Bdref	Soilquick flow capacity, mm	Plant available water, mm	Inacces-sible water, mm	Max dynamic GW store, mm	Ground water release fraction
A	1.077	84.06	294.76	267.54	100	0.1
B	1.089	81.76	303.82	290.65	100	0.1
C	0.999	81.76	303.82	290.65	100	0.1
D	1.036	81.76	303.82	290.65	100	0.1
E	0.999	84.06	294.76	267.54	100	0.1
F	1.050	81.76	303.82	290.65	100	0.1
G	0.996	76.68	291.85	281.78	100	0.1
H	0.910	76.68	291.85	281.78	100	0.1
I	0.926	81.89	296.89	277.32	100	0.1
J	0.835	95.31	298.51	252.65	100	0.1
K	1.037	84.06	294.76	267.54	100	0.1
L	1.015	100.38	310.48	261.53	100	0.1
M	0.000	0	0	0	0	0

Step 2: defining land cover types

The basic scheme of GenRiver is four 'successional stage' in a natural (secondary) succession (pioneer, early & late secondary and primary forest), four stages in an agroforestry succession (AF pioneer, early & late productive AF, post-productive AF) and additional types for irrigated rice

Land Cover Type	Pio-neer	YoungSec	Old Sec	Prim For	Water body	AF_EarlyProd	AF_LateProd	Pine	Crop	Paddy Rice	Hou-ses	Total	Mean BD/BDref
A	**0.01**	**0**	**0.07**	**0**	**0**	**0**	**0.09**	**0**	**0.23**	**0.45**	**0.14**	**1.00**	**1.077**
B	**0.00**	**0**	**0.02**	**0**	**0**	**0**	**0.29**	**0**	**0.08**	**0.37**	**0.24**	**1.00**	**1.089**
C	**0.01**	**0**	**0.24**	**0**	**0**	**0**	**0.18**	**0**	**0.27**	**0.21**	**0.09**	**1.00**	**0.999**
D	**0.01**	**0**	**0.11**	**0**	**0**	**0**	**0.22**	**0**	**0.37**	**0.13**	**0.14**	**1.00**	**1.036**
E	**0.01**	**0**	**0.02**	**0**	**0**	**0**	**0.63**	**0**	**0.09**	**0.16**	**0.09**	**1.00**	**0.999**
F	**0.02**	**0**	**0.04**	**0**	**0**	**0**	**0.28**	**0**	**0.28**	**0.26**	**0.12**	**1.00**	**1.050**
G	**0.18**	**0**	**0.10**	**0**	**0**	**0**	**0.33**	**0**	**0.20**	**0.13**	**0.05**	**1.00**	**0.996**
H	**0.17**	**0**	**0.50**	**0**	**0**	**0**	**0.12**	**0.08**	**0.06**	**0.05**	**0.03**	**1.00**	**0.910**
I	**0.05**	**0**	**0.41**	**0**	**0**	**0**	**0.27**	**0**	**0.17**	**0.08**	**0.03**	**1.00**	**0.926**
J	**0.04**	**0**	**0.87**	**0**	**0**	**0**	**0.01**	**0**	**0.01**	**0.05**	**0.01**	**1.00**	**0.835**
K	**0.02**	**0**	**0.16**	**0**	**0**	**0**	**0.16**	**0.01**	**0.19**	**0.32**	**0.13**	**1.00**	**1.037**
L	**0.04**	**0**	**0**	**0**	**0**	**0**	**0.48**	**0.01**	**0.20**	**0.21**	**0.06**	**1.00**	**1.015**
M	**0**	**0**	**0**	**0**	**1.00**	**0**	**0**	**0**	**0**	**0**	**0**	**1.00**	**0.000**
BD/BDref	**1**	**0.95**	**0.8**	**0.7**	**0**	**1**	**0.93**	**1**	**1.05**	**1.1**	**1.3**		

and urban areas

Table 3.11 Land cover types per subcatchment and resulting BD/BDref estimate

Table 3.12. Land cover types and their key influences on the water balance ('guesstimates')

Landcover type	BD/ BDref	Potential Intercep-tion (mm/day)	Relative Drought Threshold	Multiplier of Monthly Potential Evapotranspiration												Landcover Epot
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	mm $year^{-1}$
Pioneer	1	1	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	640
YoungSec	0.95	3	0.55	1	1	1	1	1	1	1	1	1	1	1	1	1280
OldSec	0.8	4	0.5	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1024
PrimFor	0.7	4	0.45	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1024
Water body	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1280
AF_EarlyProd	1	2	0.55	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	768
AF_LateProd	0.93	3	0.5	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	896
Pine	1	4	0.3	1	1	1	1	1	1	1	1	1	1	1	1	1280
Crop	1.05	1	0.7	1	1	1	1	1	1	0.7	0.3	0.5	0.5	0.5	0.8	1029
Paddy Rice	1.1	1	0.8	1	1	1	1	1	1	1	1	1	1	1	1	1280
Houses	1.3	0.5	0.7	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	256
Potential evapotranspiration, mm/month				105	109	123	144	123	118	108	103	83	92	82	90	1280

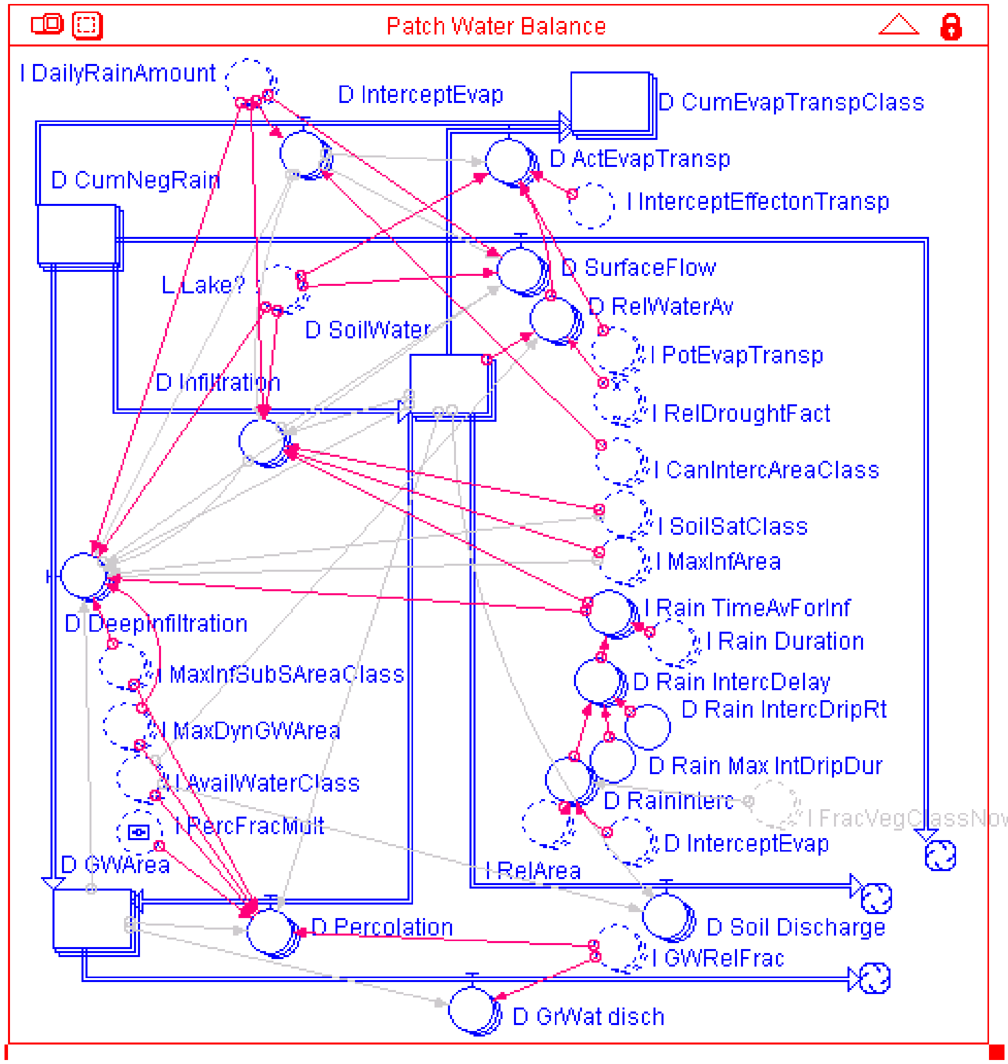


Figure 3.12. The 'core' of the model is the water balance that is maintained for all land cover types in all subcatchments (with the user defining the names and nature of land cover types and subcatchment) in response to incoming rainfall (which can be provided as subcatchment-level spatial average values on a daily basis); the model distinguishes two pools (soil and groundwater storage) and yields three types of flows: overland (surface) flow on the day of rainfall, soil discharge ('soil quick flow') on the next day and groundwater discharge with an 'exponential decay' type dynamics dominated by the I_GWRelFrac parameter

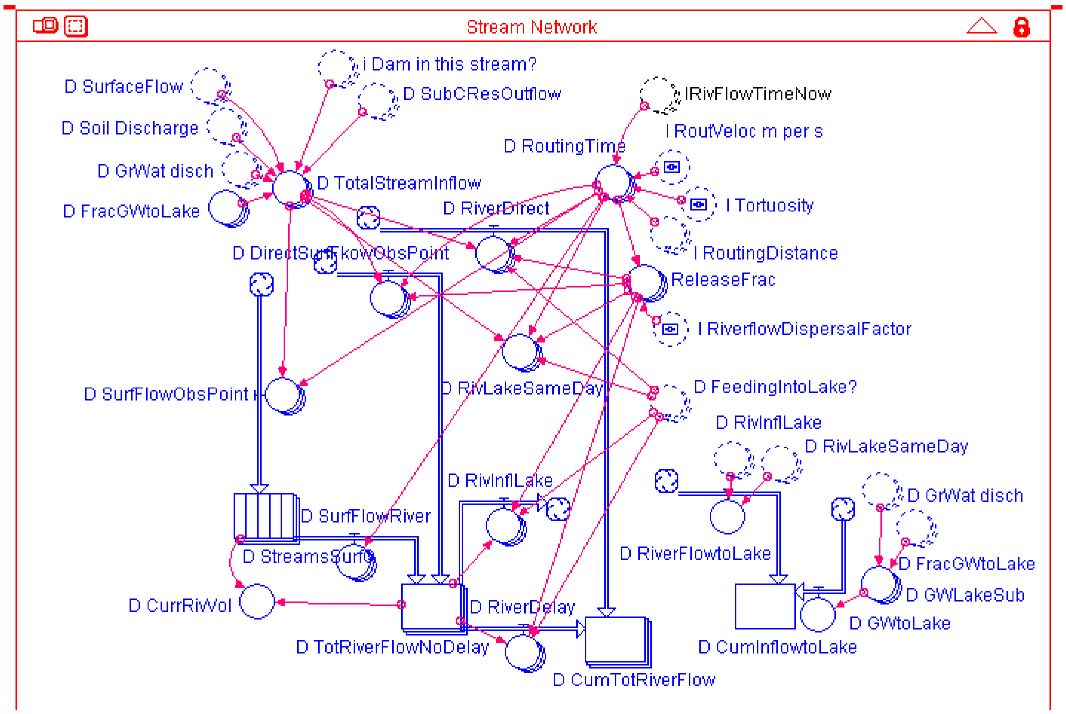


Figure 3.13. The stream network sector of the model where the incoming flows (surface flow, soil discharge and groundwater discharge) are delayed according to travel distance and flow velocity on their way to reach the various measuring points; for the Singkarak application all flows are collected in the lake

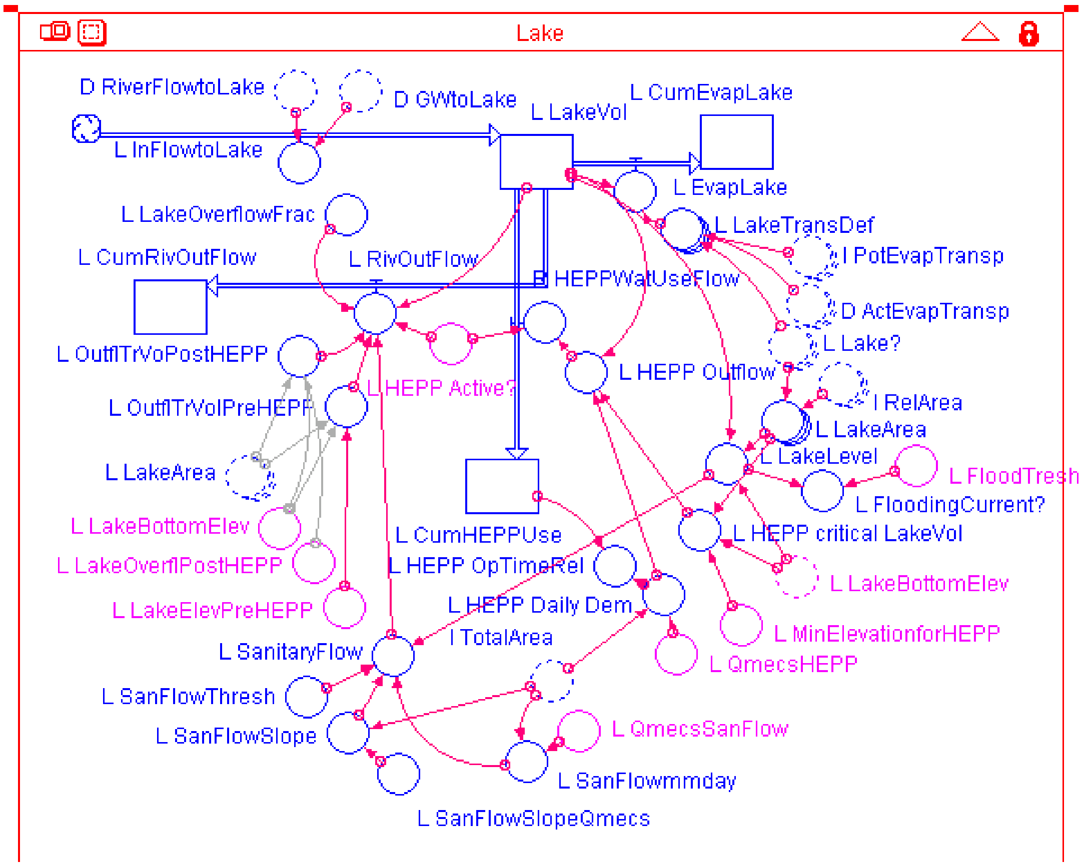


Figure 3.14. The stream network sector of the model where the incoming flows (surface flow, soil discharge and groundwater discharge) are delayed according to travel distance and flow velocity on their way to reach the various measuring points; for the Singkarak application all flows are collected in the lake

A parameter that had to be 'calibrated' was the 'L_LakeOverFlowFraction' that determines which fraction of the lake volume above a specified threshold can flow into the Ombilin river. Calibration data were obtained from the PLTA project report Annex 5.5 which contains duration curves for the lake level from 1967 to 1985. Assuming that the 1991-2002 rainfall series were not essentially different, we compared the duration curves for lake level at current land use to these frequencies. The results showed that a value of 0.1 gave good correspondence over most of the range, but that it overestimated the low frequency lake levels resulting from peak flow. The model structure was adjusted so that the overflow fraction increases with the lake level.

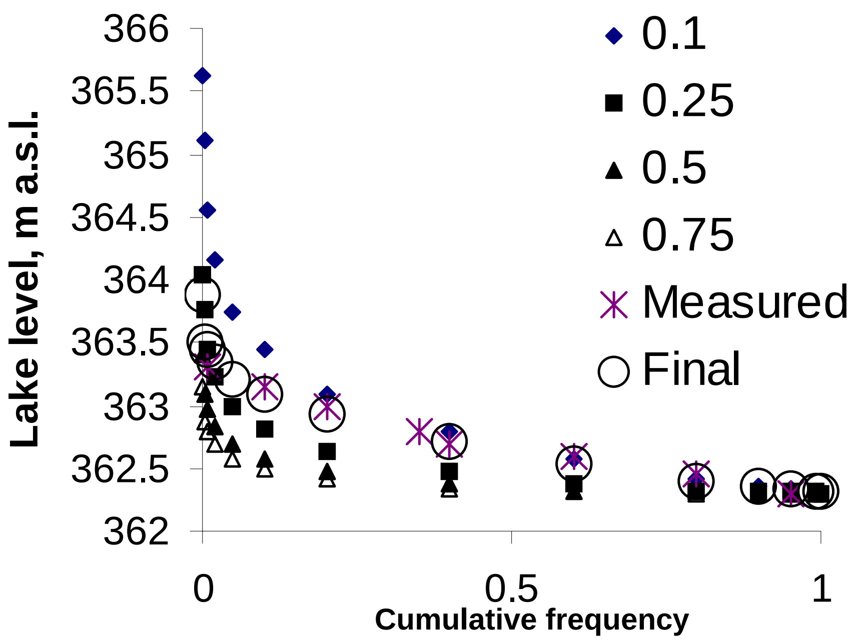


Figure 3.16. Calibration of the parameter for lake outflow, with various values for a proportionality factor compared to measured data in the PLTA project report and the final choice for a more-than-proportional outflow

The final choice was: outflow fraction = 0.1 *(1+LevelAboveThreshold^4)

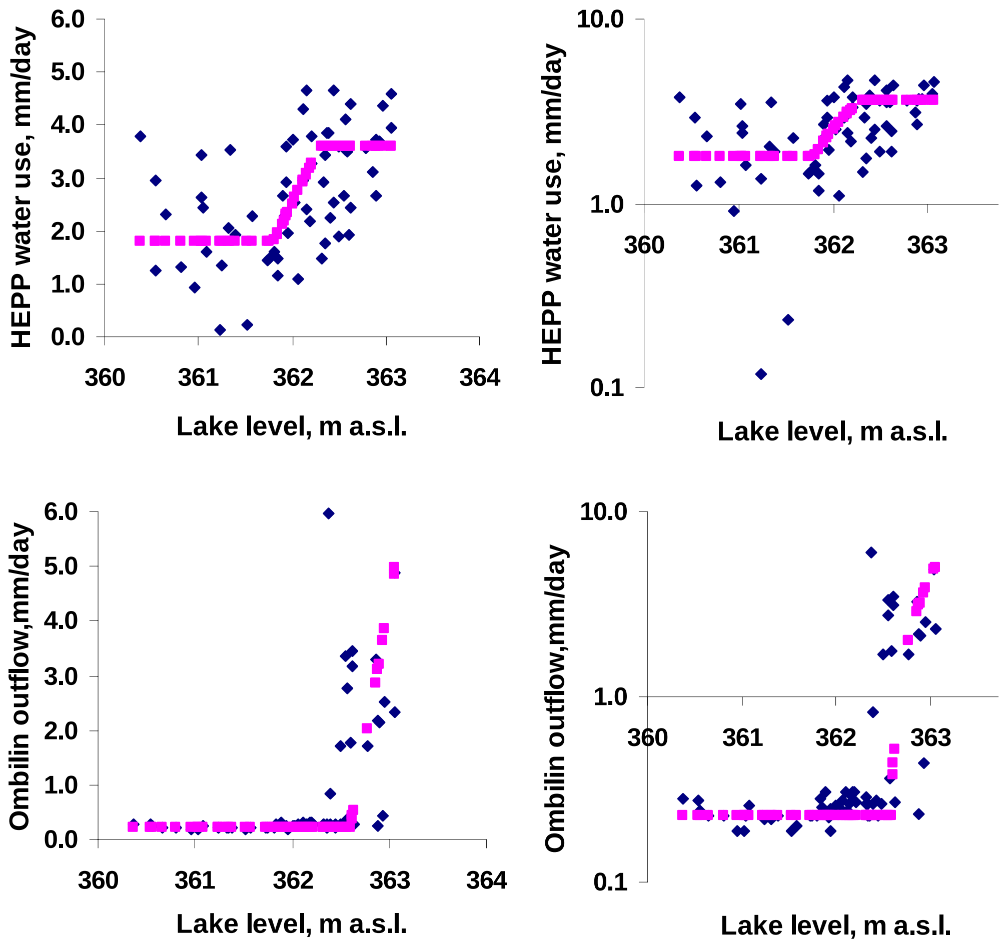


Figure 3.17. Monthly mean performance of the PLTA Singkarak in the period January 1999 – May 2004 (65 months) in relation to the mean lake level records: the upper two panels give the actual HEPP water use relative to the target use of 47.1 $m^3 s^{-1}$ (or 3.585 mm day^{-1} when expressed over the whole catchment area as we do), the lower two the 'sanitary' flow in the Ombilin river relative to the target of 3 $m^3 s^{-1}$ (or 0.228 mm day^{-1} when expressed over the whole catchment area as we do), with additional flow according to the rules for the pre-HEPP situation, but with an increase in the reference lake level of 0.3 m (NB the two panels on the right hand side use a logarithmic scale)

Actual use of water for the PLTA turbines is not at full planned capacity for a number of reasons:

1. Technical reasons, including inspection, maintenance or repair of machinery
2. Saving on water in dry periods, when expected inflows for the coming period are less than the expected needs
3. Low levels of the lake, below the threshold set for intake

In the current form the model only takes reason 3 into account.

Analysis of flow persistence

A final parameter can be obtained from existing records of river flow. By comparing the flow of the river on any day with that on the day before we can get an estimate of the continued water supply. Figure 3.18 shows some examples of the flow records of the Suman river, the largest inflow into Lake Singkarak. The river has a very 'flashy' nature, with sharp peaks followed by rapid decline in the rate of flow.

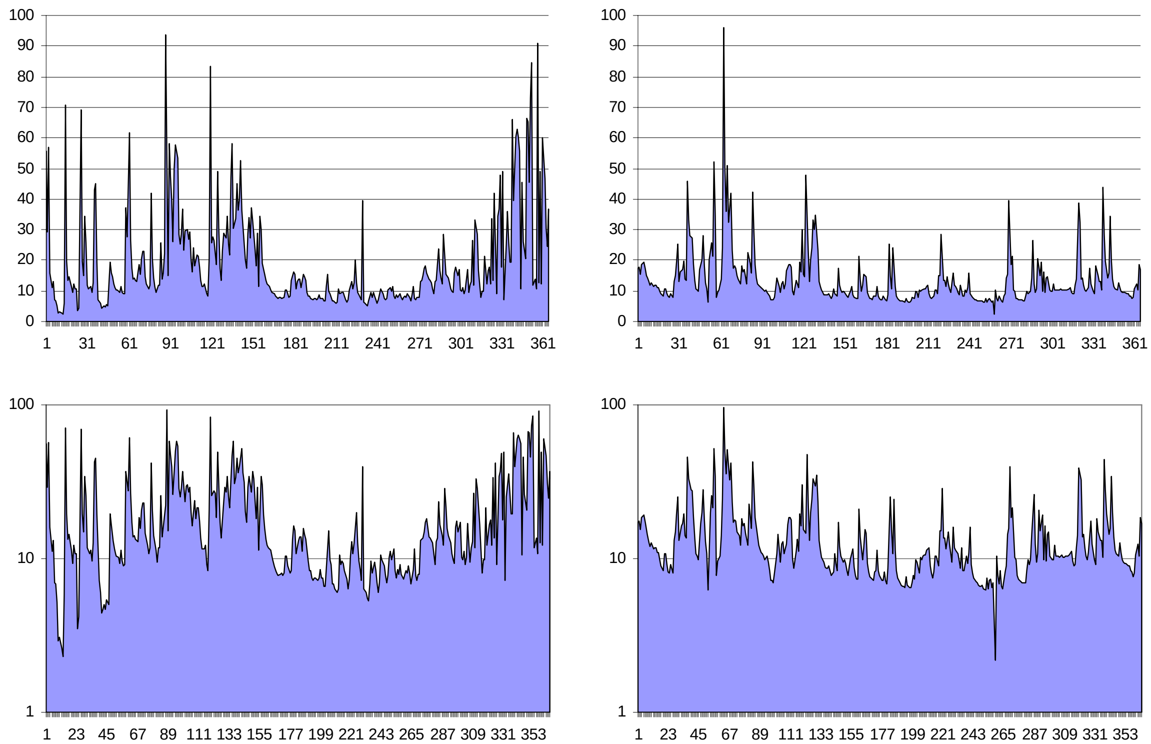


Fig. 3.18 . Example of the flow records for the Suman river for two years (upper panels on linear scale, lower panels on logarithmic scale

In a plot of Q_t versus Q_{t-1} the vast majority of the points lies above the line $Q_t = 0.5Q_{t-1}$ indicating a flow persistence of about 50%. All points above this line probably reflect rainfall events between times t-1 and t. This implies that about 50% of the available (ground)water stock flows in the river at any given day. As suggested in Fig. 3.19, there is no evidence that the flow persistence of the Suman river has changed over the period 1990 - 2002. A small fraction of the points lies between a slope of 20 and 50%, suggesting that a part of the total river flow derives from a subcatchment with a much lower flow persistence, that occasionally receives rainfall on days that the rest of the catchment does not.

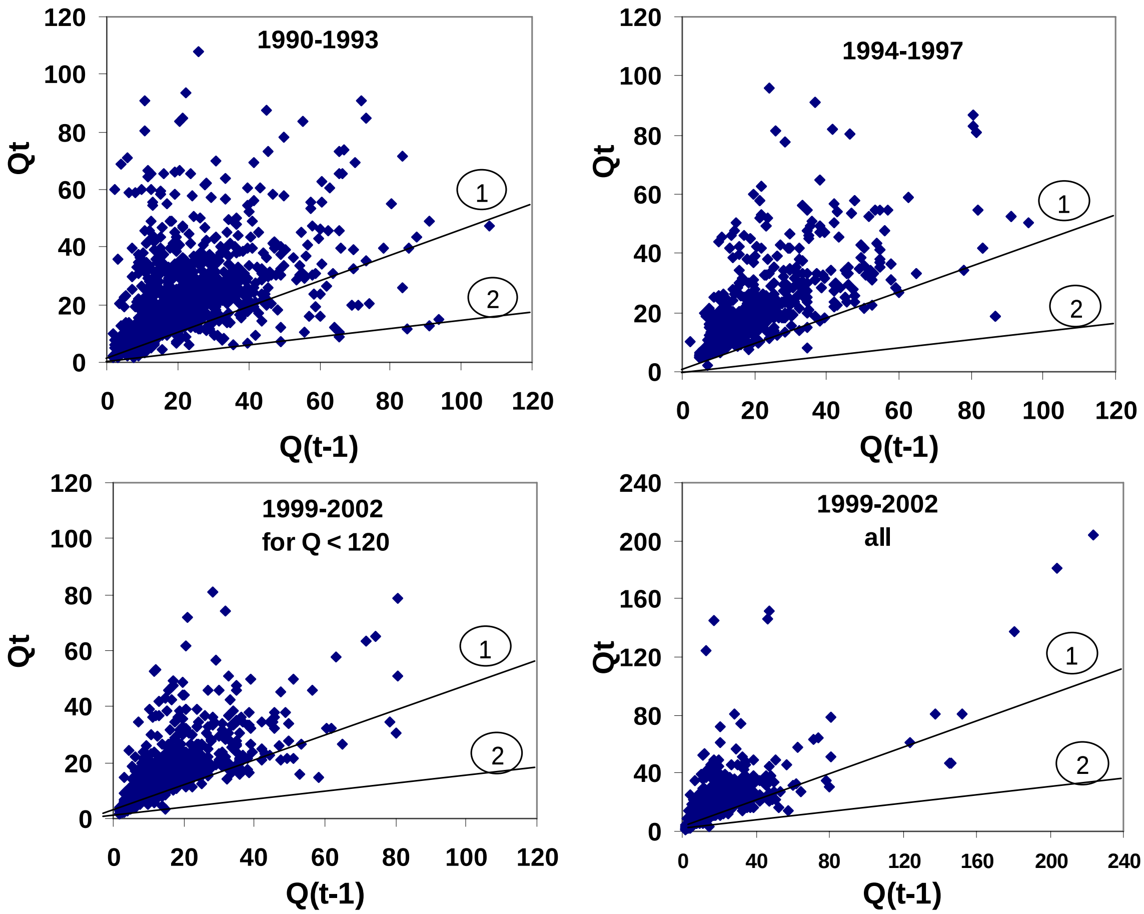


Figure 3.19. Flow persistence of the Suman river in three time periods (please note that the 1999-2002 period contained higher flow values and is shown twice: once for the same data range as applied in the 1990-1993 and 1994-1997 periods, once for the full range); lines 1 and 2 indicate a flow persistence of 0.5 and 0.2, respectively)

3.4.3 Default runs for 'current Land use'

For the simulation rainfall data were used for the 1992 – 2002 period taken from the Saning Bakar rainfall station two out of these 11 years had less than 2000 mm of rain, five had more than 3000 mm

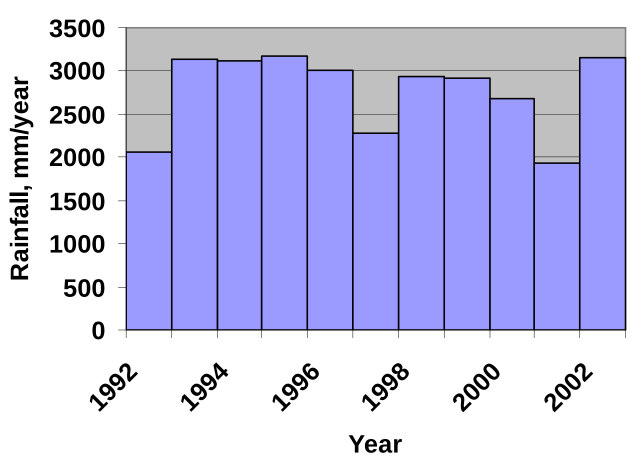


Figure 3.20 Yearly totals for the daily rainfall data from the Sumani station used for the GenRiver simulations

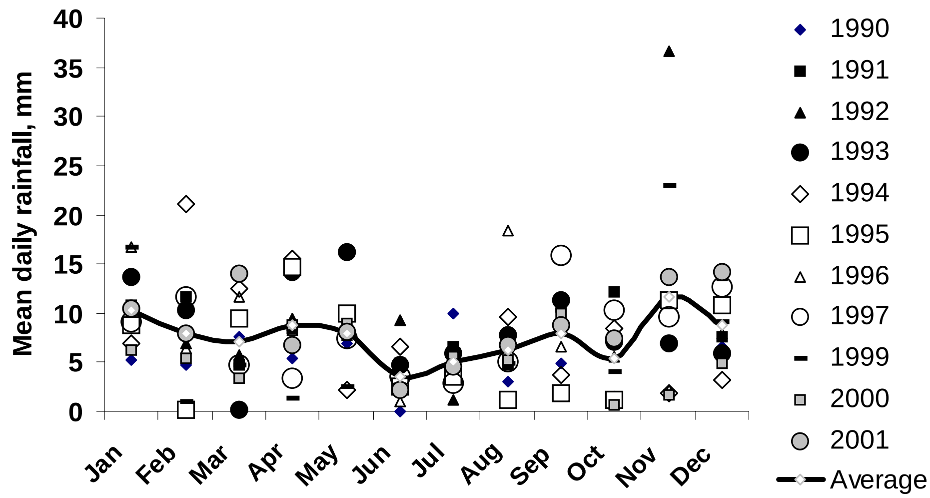


Figure 3.21 Mean daily rainfall per month of year and the spread between years

The runs for the default parameterization suggested that the amount of water available for electricity production depended on the annual rainfall (with 74% of the variance between years accounted for)

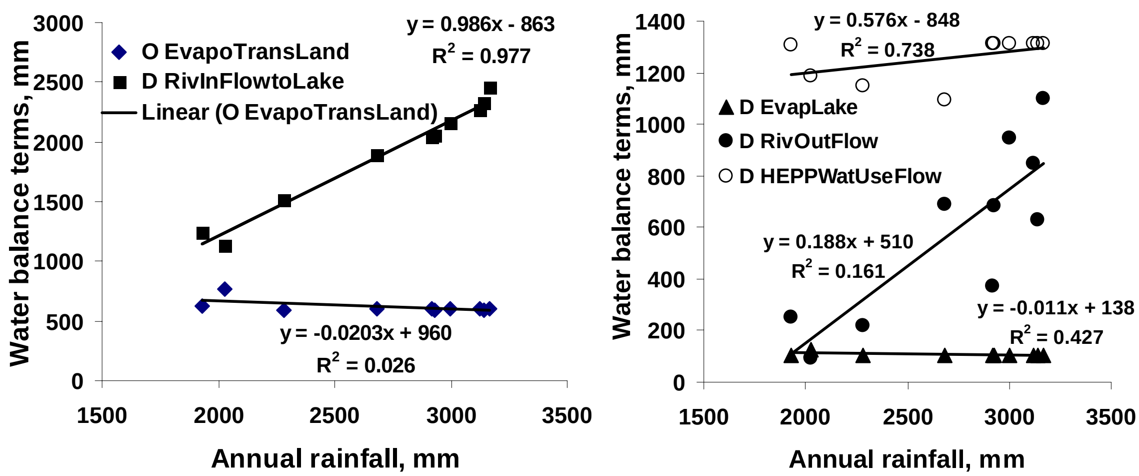


Figure 3.22.Relationship between terms of the yearly water balance and the annual rainfall

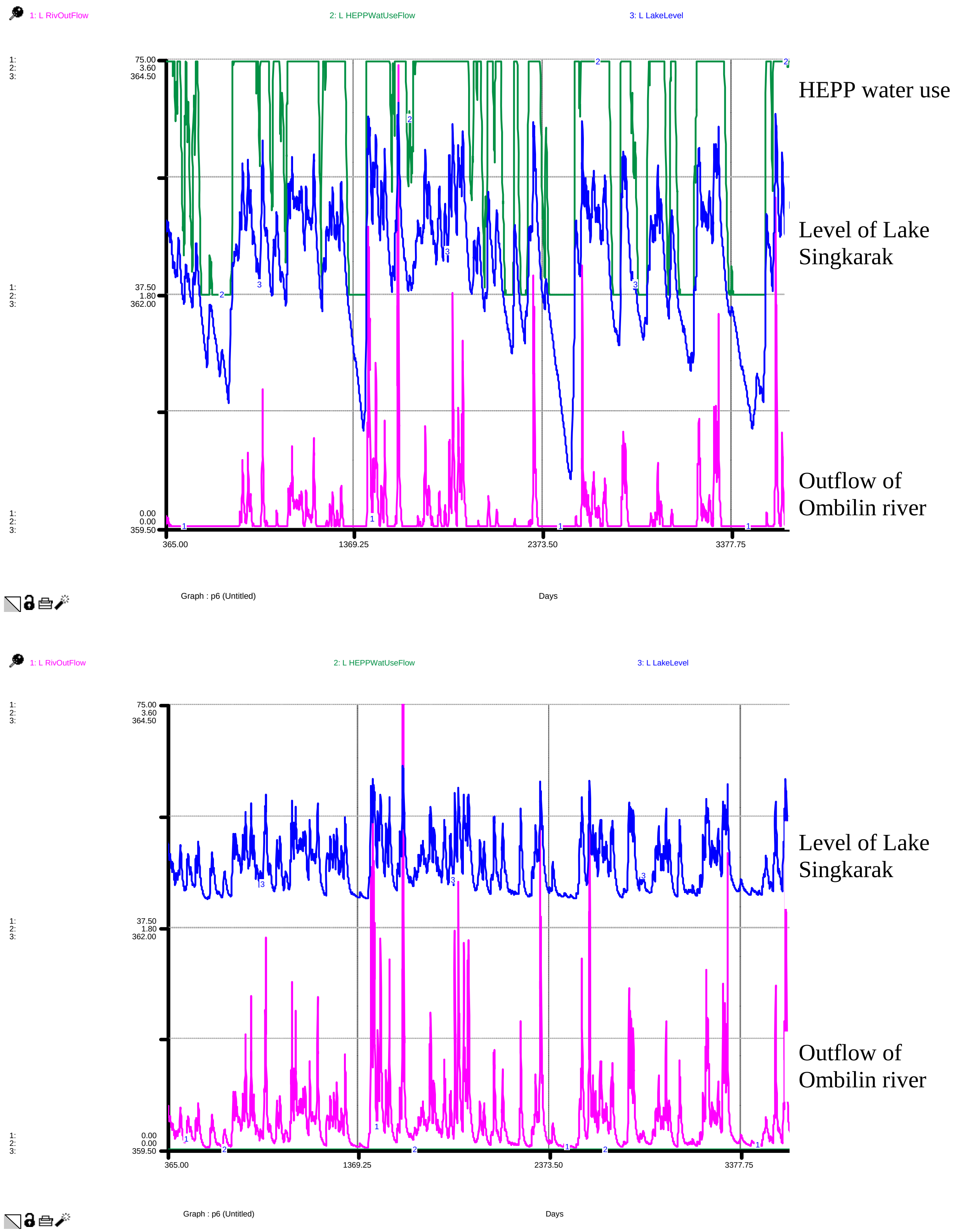


Figure 3.23. Simulation of the level of Lake Singkarak, outflow of the Ombilin river and water use by the PLTA (HEPP) with rainfall data for 1991-2002, in a scenario with (above) and without (below) HEPP

3.4.4 Model predictions for 'scenarios' of land cover change

Scenarios: the full spectrum of land use change at nested scales

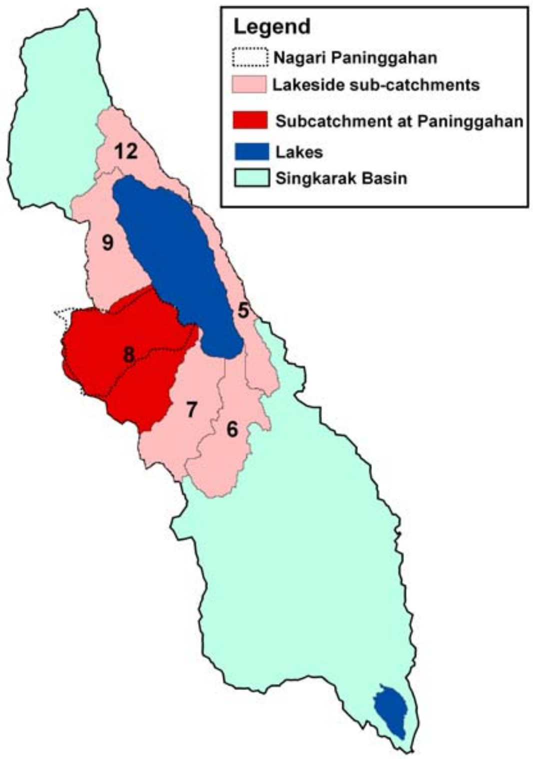


Figure 3.24. Nested scales for studying scenarios of land cover change: Paningahan subcatchment, all lake-side subcatchments and the Singkarak catchment as a whole

The model was used for exploring a wide range of land cover scenarios:

1. a series that explored the hypothetical situation with 'natural forest' for the catchment as a whole, the Lake-side subcatchments or Paningahan
2. degradation series that replace all cropland and agroforestry by 'pioneer;' vegetation (Imperata grassland), with or without additional compaction of the soil under the grassland and with or without effects of a 'weedy lake' (representing a situation with water hyacinth (Enceng godok) expansion on the lake
3. a series representing Pinus reforestation on all lands that are nor rice fields, forest or houses
4. a series of climate change scenarios.

Details are given in Table 3.112, results in table 3.13.

Table 3.12 Scenarios exploring the extremes of land use change

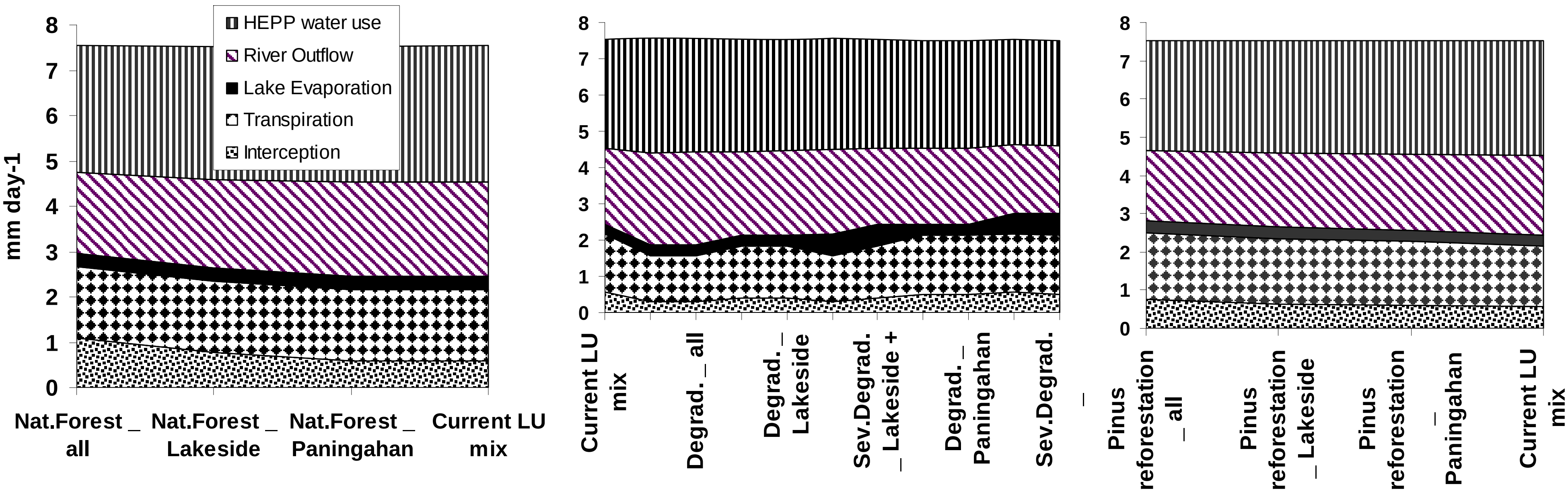
Scenario	Whole Singkarak catchment	All lake-bordering subcatchments	Paninggahan	Lake
1. Natural forest	1A. All primary forest	1B. All primary forest, rest current LU mix	1C. All of Paningahan primary forest, rest current LU mix	
2. Current LU mix	Default	Default	Default	
3. Full degradation	3A1. All LU except Ricefields & Houses replaced by 'pioneer' 3A2. Idem, with compacted[1] soil 3A3. As 3A2	3B1. All LU except Ricefields & Houses replaced by 'pioneer'; rest default 3B2. Idem, with compacted[1] soil 3B3. As 3B2	3C1. All LU except Ricefields & Houses replaced by 'pioneer'; rest default 3C2. Idem, with compacted[1] soil 3C3. As 3C2	-- -- Doubling evapo-transpira-tion
4. Full refores-tation	4A. All LU except SecForest, Ricefields & Houses replaced by Pine	4B. All LU except SecForest, Ricefields & Houses replaced by Pine; other subcatchments default	4A. All LU except SecForest, Ricefields & Houses replaced by Pine; other subcatchments default	
5. Weedy lake				Doubling evapo-transpira-tion
6. Reduced rice production	6A1 – 8 months ET 6A2 – 4 months ET	6B1 – 8 months ET 6B2 – 4 months ET	6C1 – 8 months ET 6C2 – 4 months ET	
7.1 50% more rain (Clim. Change)	Default	Default	Default	
7.2. 50% less rain (Clim. Change)	Default	Default	Default	

1. Compacted soil: BD/BDref = 1.3

Table 3.13. Results of GenRiver 1.1 simulations for the various scenarios of Table 3.12

	Max	0.465709	0.629832	0.142624	30382	4338	7036	2345	10290	12594	0.874755	0.7303	0.997349
Simulations at current rainfall	Mean	0.279795	0.5885	0.131705	30294.9	2197.5	6208.25	1407.4	8414.85	12005.35	0.833882	0.688263	0.977526
	Min	0.236163	0.428529	0.105762	30233	1143.1	5160	1173	7155	11226	0.779783	0.63476	0.936346
		Flow pathways			Water balance terms in mm over 11 years						HEPP performance (fraction)		
Scenario	Code	SurfQuikflow	SoilQuickFlow	BaseFlow	Cum Rain	Cum IntercE	Cum Transp	CumEvap Lake	CumRiv OutFlow	Cum HEPPUse	Mean	Worst year	Best year
Nat.Forest _ all	1A	0.465709	0.428529	0.105762	30,382	4,338.00	6,374	1,173	7,155	11,226	0.779783	0.63476	0.936346
Nat.Forest _ Lakeside	1B	0.381595	0.497664	0.120741	30,280	3,150.10	6,255	1,173	7,814	11,813	0.820518	0.677633	0.962858
Nat.Forest _ Paningahan	1C	0.296513	0.567853	0.135634	30,298	2,402.10	6,316	1,173	8,299	12,051	0.837069	0.690573	0.982903
Current LU mix	2	0.287009	0.575585	0.137406	30,314	2,340.80	6,316	1,173	8,356	12,072	0.838518	0.691953	0.984659
Sev.Degrad. _ all	3B1	0.241259	0.624535	0.134206	30,367	1,143.10	5,160	1,173	10,246	12,594	0.874755	0.7303	0.997349
Degrad. _ all	3A1	0.309629	0.567157	0.123214	30,367	1,143.10	5,160	1,173	10,290	12,550	0.871727	0.728649	0.993081
Sev.Degrad. _ Lakeside	3B2	0.25788	0.599497	0.142624	30,266	1,648.30	5,716	1,173	9,300	12,375	0.85958	0.714459	0.996506
Degrad. _ Lakeside	3A2	0.298821	0.570085	0.131094	30,266	1,648.30	5,714	1,173	9,341	12,337	0.856888	0.712664	0.992183
Sev.Degrad. _ all + WL	3C1	0.241259	0.624535	0.134206	30,367	1,143.10	5,160	2,345	9,368	12,298	0.854199	0.707165	0.994422
Sev.Degrad. _ Lakeside + WL	3C2	0.25788	0.599497	0.142624	30,266	1,648.30	5,716	2,345	8,428	12,071	0.838465	0.690582	0.991316
Sev.Degrad. _ Paningahan	3B3	0.236163	0.629832	0.134005	30,233	2,042.90	6,551	1,173	8,375	12,036	0.836003	0.690168	0.979974
Degrad. _ Paningahan	3A3	0.250706	0.619657	0.129637	30,233	2,042.90	6,551	1,173	8,392	12,019	0.834857	0.689529	0.975812
Weedy lake	4	0.287009	0.575585	0.137406	30,314	2,340.80	6,316	2,345	7,552	11,696	0.812422	0.665187	0.971813
Sev.Degrad. _ Paningahan + WL	3C3	0.236163	0.629832	0.134005	30,233	2,042.90	6,551	2,345	7,570	11,662	0.810017	0.664668	0.966012
Pinus reforestation _ all	5A	0.259991	0.609488	0.130521	30,331	3,036.60	7,036	1,173	7,395	11,601	0.805769	0.663527	0.959042
Pinus reforestation _ Lakeside	5B	0.25329	0.615134	0.131577	30,272	2,559.90	6,895	1,173	7,770	11,812	0.820452	0.675668	0.967368
Pinus reforestation _ Paningahan	5C	0.25053	0.618288	0.131183	30,265	2,368.20	6,803	1,173	7,977	11,886	0.825568	0.680204	0.970388
Current LU mix	2	0.287009	0.575585	0.137406	30,314	2,340.80	6,316	1,173	8,356	12,072	0.838518	0.691953	0.984659
Only two crops of rice	6A	0.248913	0.620556	0.130531	30,265	2,284.90	6,665	1,173	8,145	11,944	0.829591	0.682804	0.971918
Only one crop of rice	6B	0.248579	0.621096	0.130324	30,265	2,284.90	6,594	1,173	8,168	11,992	0.832949	0.682804	0.971918
50% less rain	7A	0.282698	0.468882	0.248419	15,133	2,031.80	6,314	1,173	955	4,490	0.311854	0.179452	0.628258
25% less rain	7B	0.250519	0.599039	0.150442	22,699	2,192.30	6,678	1,173	2,851	9,622	0.668364	0.550961	0.821353
Default rainfall	2	0.287009	0.575585	0.137406	30,314	2,340.80	6,316	1,173	8,356	12,072	0.838518	0.691953	0.984659
25% more rain	7C	0.256081	0.608522	0.135397	37,832	2,344.70	6,730	1,173	14,616	12,920	0.897439	0.763529	0.999556
50% more rain	7D	0.266057	0.583189	0.150754	45,398	2,386.10	6,730	1,173	21,585	13,480	0.936336	0.816033	1

Figure 3.25 Mean annual water balance for the various scenarios of Table 3.13



The partitioning over baseflow, soil quick flow and surface quick flow is remarkably insensitive to total rainfall amount. With the current parameter settings the inflow to groundwater is close to its maximum capacity…

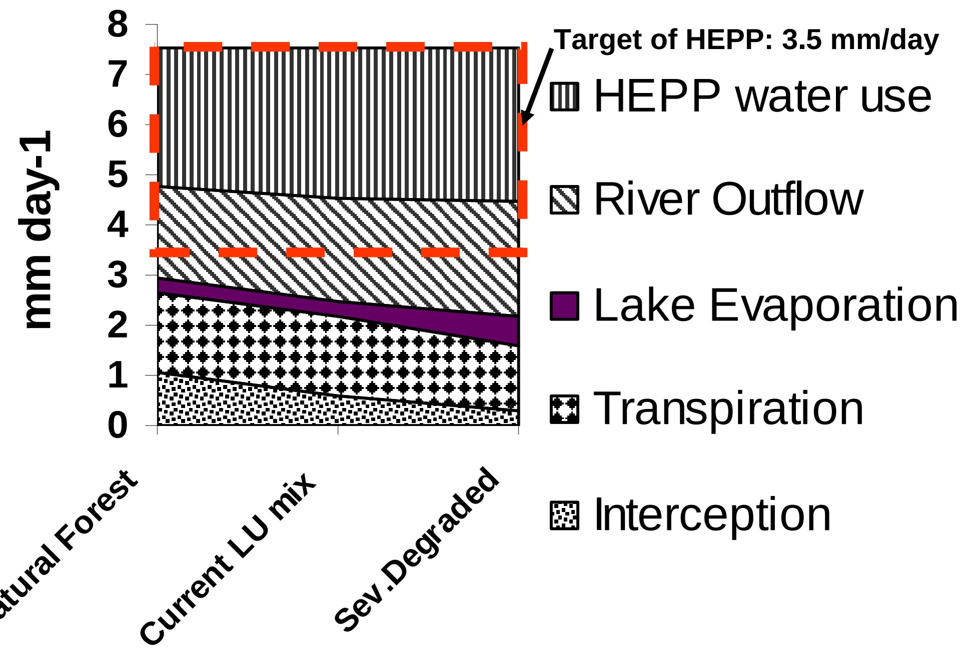


Figure 3.26. Average daily water balance for the simulations over the 1991-2002 period under the assumption that HEPP is operational, for a range of land cover scenarios (see table 3.12 for definitions); the pane in the upper left compares a hypothetical situation with natural forest cover on the whole catchment, the Lake-side subcatchments or Paningahan alone with the current land use mix; the upper right compares various 'degradation' scenarios, with or without effects of a 'weedy lake' filled with water hyacinth and transpiring at double the current rate; the lower left panel compares *Pinus* reforestation of all crop + fallow lands at the three scales; the lower right panel compares modifications of current rainfall regime

The results for the various scenarios show that the likely effects of land cover change on the partitioning of the water balance as well as on the performance of the PLTA are small – at least relative to the inter-annual variation in rainfall. Systematic climate change, here represented by using multipliers of 0.5, 0.75, 1, 1.25 or 1.5 on daily rainfall records for the 11 year period, is expected to have a strong impact on PLTA performance: with less rainfall the PLTA is likely to be affected more than proportionally, while a considerable increase in rainfall is needed before the average PLTA performance reaches above 90%.

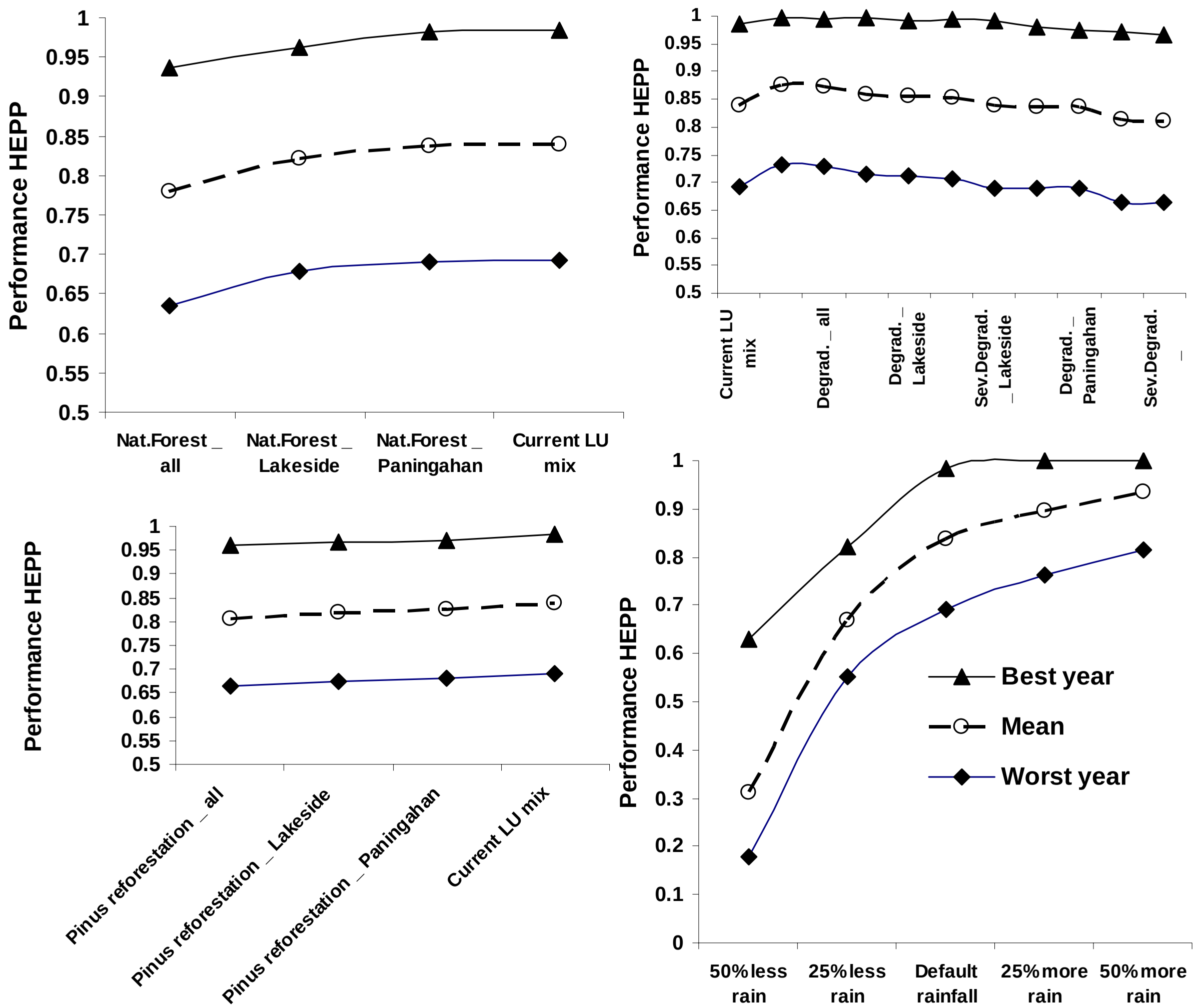


Figure 3.27. Simulated performance of the PLTA Singkarak in the best, the worst and an average year of the 1991-2002 rainfall data, for the various land cover scenarios.

The GenRiver 1.1 simulations presented here are only indicative of the consequences of the assumptions made. With a modified set of parameters (assumptions) on the plot-level impacts of land cover types (e.g. the interception or drought tolerance parameters), results will shift. The relative impact of the land cover change scenarios, however, is unlikely to change drastically.

Improvements to the model may be needed first of all in the representation of the limestone areas and their subsurface groundwater flows. Our assumption that the Singkarak basis is hydrologically ‘tight’ may need to be checked, as part of the limestone areas on the Bukit barisan ridge might drain westward rather than towards the lake.

Rainfall is the dominant variable in simulations of this kind, and the use of single-station rainfall to represent the catchment as a whole is very unsatisfactory. At the time of completion of this report efforts to use the SpatRain program for a representation of spatially differentiated rainfall were still in progress.

4. Discussion and conclusion

4.1 Differences and similarities in concern from different stakeholder: LEK, PEK and MEK comparison

4.1.1 Comparison between stakeholder groups on trees, soil and water flows

Although in general the knowledge between the four groups interviewed had similar constructs, a few interesting differences between these groups emerged. Women farmers say that the quantity of available water is mainly influenced by season and trees; including the pines, inside forests help retain water inside the soils. They did not perceive that pine trees are any different from other broadleaf species in terms of making soil dry and thereby affecting water availability.

Informal government group also agree that trees help to hold water in the ground reducing runoff and soil erosion. Male farmers also reported that water quantity is influenced by season, land coverage, soil type and trees type on land. They expect that replacing pines with other tree species as in natural forests is better for soil and water conservation.

The government officials also mentioned season, land coverage, and soil type and tree type as influencing factors to water availability. Reforestation is seen as increasing land coverage that can decrease evaporation.

4.1.2 Comparison between stakeholder groups on flooding

Women farmers mentioned that flooding around the lake is caused by an increase in the water level in the lake. This happens only in the rainy season and because the outflow of water is closed. The non-government official had a similar view. The amount of water in the lake increases because of higher intake from fast flowing feeder rivers. Fast flow also causes rivers to meander. Amount water in the river is, however, also influenced by presence of trees in forest and riparian areas upstream.

Government officials said that forest clearing in the south of Singkarak Lake is causing most problem of flooding. This is mainly because of the forests that can hold water and reduce flooding are now lacking. Male farmers have similar opinion about factors influencing flooding – affecting mainly rice crops - damaging field and irrigation channels.

4.1.3 Comparison between stakeholder groups on water quality

Female farmer group opined that water quality of Singkarak Lake has decreased due to debris (mostly household and market waste) and soils carried by Lembang and Sumani rivers. The population of Bilih fish has been affected as the species like clean and moving water. However, it was also noted that the use of dynamites and fishing nets with smaller mesh size has contributed significantly to the decline in population of Bilih fish. Traditionally Bilih fish were caught using tools made of bamboo, called *hirok* and *alahan*.

Government officials expressed their opinion that the primary reasons for declining lake water quality are the debris from market and households and clearance of forests upstream (erosion problem). Female farmers have a similar opinion. Non-government officials agreed that trees inside forests have an important role in maintaining the environment.

The selected stakeholder groups (male farmers, female farmers, government officials and non-government leaders) were found appropriate and relevant for studying the hydrology related issues in Paninggahan sub-catchment. In general, there was similar knowledge held by all the groups and subtle differences were noted in some cases.

Recently, under the re-greening program, the government has encouraged planting of pine trees in the upper slopes of deforested hills. This was obviously perceived as having a negative effect on the water retaining capacity of the area. Broadleaved species, particularly the native species are considered by farmer as far superior compared to the more commonly planted pines in terms of their contribution to holding water in soil and reduces evapo-transpiration from their leaves. However, the women farmers did not see any difference between pine and other trees.

The concept of evapo-transpiration among most people in the area is an interesting encounter as other more detailed studies of local ecological knowledge have not reported this concept among the local people. However, the concept of water holding capacity by larger leaved species leading to bigger water drops causing more soil erosion was reported. The long and deep roots of pine that are able to 'search out' deep water were also perceived as having negative character. The dried needles were considered a fire hazard. Limited time in the current study did not allow a deeper investigation of other species and inter-species variation in evapo-transpiration and other aspects.

Flooding is a problem only when heavy rains occur in the upstream. The rain is less problematic in stony and limey soils as water permeates through the soils to reach the ground water. Flooding is becoming a problem also due to the rising lake floor caused by siltation. The closing of the exit by the PLTA dam has made the situation worse as the rising lake ends up in the rice fields close to the lake. The effects are damage to the rice crops and to the dikes in the field and irrigation channels. There was a general consensus that trees along the rivers and forest areas are helpful in reducing flooding and siltation.

The quality of lake water is seen as worsening. The debris, through directly or indirectly by human activities (domestic and market waste), in the river is the main problem. The closure of water exit prevents this debris from being washed away and remain on the surface of the lake. The increased turbidity is adding to the problem. The impact is on the population of Bilih fish, an important commodity in the area. The use of more intensive fishing techniques (smaller nets and fish poisons) is also contributing to the reduction of Bilih fish population.

Overall, the knowledge and perception of different stakeholder groups in Paninggahan reflect reasonable understanding of the natural processes related to quality and quantify of information gathered. However, it was noted, as confirmed by a number of people interviewed, that Paninggahan is fortunate not to suffer as badly as other sub-catchments from environmental destruction. The upstream catchments as well as the riparian areas are still relatively well vegetated and there are no major areas of destruction. This probably resulted in only a general understanding by the local people. Perhaps if the study had been carried out in area with more serious problem of landslides, erosion, less conducive soils and steeper and barren slopes may reveal more drastic and in-depth knowledge and experience. Hence, it is recommended that an more detailed investigation of local people's knowledge and perceptions be carried out that includes other villages and sub-catchments around Lake Singkarak.

4.1.4 Discussion on methodology

The rigorous approach of local ecological knowledge (Dixon et al 2001) was adapted for a more rapid appraisal of local people's knowledge about hydrology. The method took nearly two weeks to explore, plan and implement, was reasonably successful in clarifying the general understanding and perception of the local people. The time limitation was self-imposed to see if such local knowledge can be articulated from key stakeholder groups over a short period, as a part of Rapid Hydrology Assessment. Although initially planned, the reference sites in the landscape (e.g. landslides, road construction, flood areas, forests and agroforests) were not visited by all groups. Had it been done, a clearer comparison between the different groups' knowledge and perceptions would have been possible.

Finally, the study, planned and conducted over a short period has revealed some interesting results that have implications on future research and development programs. Examples include the use of pines in tree planting programs, the need to better understand the role of pine in hydrology issues, the role of dams in local people's livelihood options. However, it also confirms the existing understanding among local people of trees in forests, along rivers and on farms in relation to hydrology. But perhaps only the surface has been explored.

Baseline spatial data necessary for hydrological study in Singkarak Basin, have been collected, processed and analyzed to comply with the spatial description of the area in RHA as well as of obtaining necessary parameters for GenRiver model inputs.

To serve the 'rapid' concept of the study, secondary data with relatively coarse scale are aimed, so is the free-downloadable low-resolution elevation information from SRTM-3 DEM. The generation of land cover classes from raw Satellite Imageries is in relatively broad classes, but is sufficient to serve the purpose.

Further accuracy and reliability assessments of the data and information produced are needed especially if they are to be used for higher detailed analyses and field-based studies.

4.2 Is there a basis for 'environmental service' payments?

Basic assumption for the 'buyer': there is an actual 'service' that will only be provided if we pay…

The construction of a case for environmental service payment' case for Lake Singkarak on the basis of hydro-electricity is essentially based on the logical links in Figure 4.1.

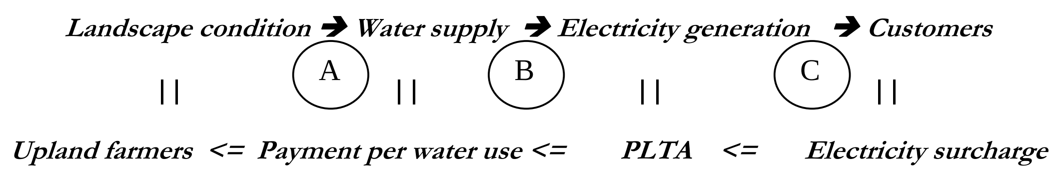


Figure 4.1 Schematic logic of the case for environmental service payments

If any of these steps is weak or non-existent the 'case' falls apart. Let's start at the end of the chain with step C. Blackouts are common in West Sumatra, at times that the electricity generation does not match demand and there is insufficient capacity in the grid connecting Sumatran power generators to make up. Some of these failures are linked to repair or malfunction of equipment at the PLTA, some are due to shortage of water in Lake Singkarak. Consumers don't like blackouts, so one may expect that there is a 'willingness to pay' for any measure that reduces or avoids blackout (the level of this 'willingness to pay' has to be further explored). There is, however, no major problem to be expected at step C.

Step B is also clear: water supply to the lake, especially during dry periods, is important to the well functioning of the PLTA. They have a contractual obligation to the Provincial Government to pay per cubic meter of water used and this is affordable as it was part of the economic feasib ility study of the project.

The problems start with step A, the relation between landscape condition and water supply to the hydroelectricity company. The water balance model does not support the perception that shortages of water supply in dry periods are due to 'deforestation' or that the situation can be improved by 'reforestation'.

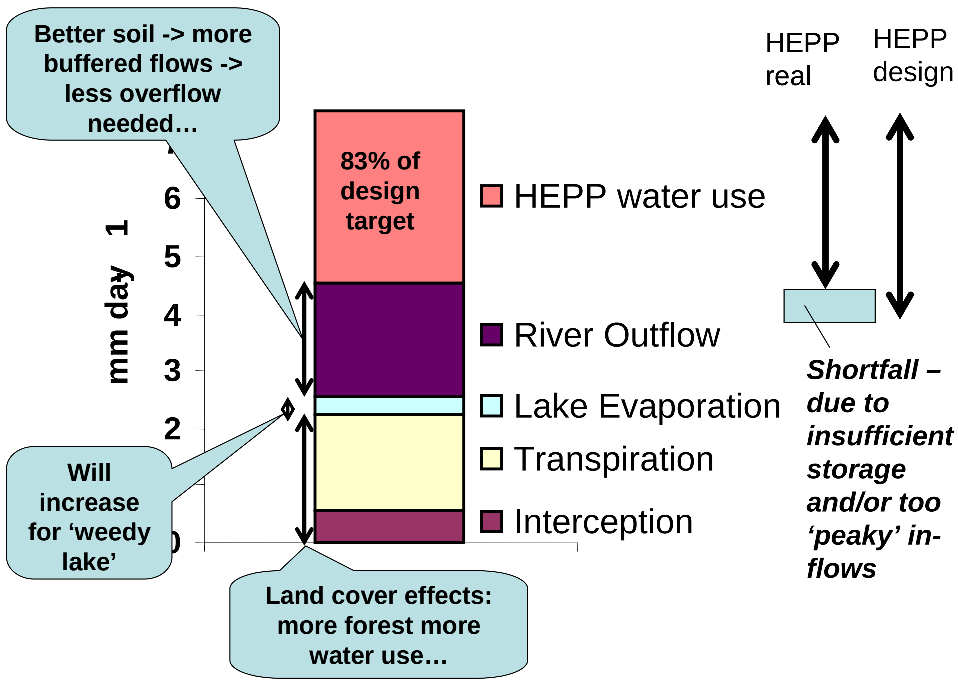


Figure 4.2 Summary of the results for the water balance model

The water balance model suggests that the overall shortfall of water for electricity generation is a problem of timing: the storage capacity of the lake at the peak of the rainy season is insufficient to retain the water, so it is allowed to overflow into the Ombilin river. The water use of 3 cm of lake level per day (3 mm/day for the basin as a whole) when the hydroelectricity plant operates at full capacity leads to a depletion of the 'active volume' of about 2 m in little over 2 months, in the absence of inflows. The main issue is whether the landscape as a whole could buffer flows at the monthly time scale to provide the more even flows that are needed. In our analysis this can not be expected for the volumes of water required. It can almost certainly not be achieved by changes in a relatively small part of the whole basin, as represented by the Paningahan stream. The most direct effect of land degradation under the high rainfall regime of West Sumatra is likely to be a shift from 'soil quickflow' to overland flow. Although potentially dramatic in its consequences for erosion, the effect of the volume flow of water is relatively small and the shift in time is only a matter of hours or days. The Singkarak lake is sufficiently buffered at that time scale. At the weeks/months timescale where more buffer is needed we expect little change from land cover change. Land cover change as such has little bearing on water supply to the lake, because the buffering provided by the lake volume is sufficient to make shifts in the flow pathways of water to be insignificant. What matters is the total water supply, and the relatively small difference in evapotranspiration between land cover types (all are essentially evergreen in this climate and all have a sufficiently high leaf area index for most of the year to approach potential evapotranspiration as long as the soil water supply lasts).

Effects via water quality and weed development on the PLTA water availability are relatively small as well, although a weedy lake will have other complications for the PLTA. Yet. Maintaining water quality in the lake is important for virtually all stakeholders. Priority actions would have to focus on the rivers and streams that currently carry the highest sediment, nutrient and organic pollutant loads – most noticeably the Sumani river that drains the largest area of intensive horticulture and passes by a medium-sized town. Pollution control at point source level will have to complement efforts based on land cover.

A basic assumption for 'payments for environmental services' is that the supply of these services does depend on activities of those 'rewarded'. For the PLTA this assumption is not supported by much evidence….Payments made by the PLTA may have various types of rationale:

- Compensation for damage caused by the HEPP project, to the farmers along the Ombilin river whose waterwheel irrigation systems are disturbed as well as to the farmers with rice fields surrounding the lake affected by increased flooding
- Shared responsibility for maintaining the water quality in the lake as the HEPP project modified outflow rates and increases debris accumulation
- Payments of tax to local government
- Goodwill enhancing payments to the local community
- Payments for environmental services conditional to the delivery of these services

At this stage the evidence for the last component is relatively weak, and almost absent for the scale level of a single nagari. Efforts of all lake-side nagari's will be needed to deal with the issues of lake water quality, while the other inflows to the lake need at least equal attention.

4.3 An alternative 'reward' model for Paninggahan?

In the various discussions with the Wali Nagari of Paninggahan and the villagers involved, a keen interest has been expressed in support for better access to the 'upper Paninggahan valley'. The village has land that is recognized as theirs as enclave within the state forest land. The valley used to be covered by coffee gardens, but these are now largely overgrown by secondary forest – after the area was abandoned in 1958 s in the context of the political events of the time. Given that the Paninggahan stream is the cleanest one of the whole basin, would it be possible to re-develop these coffee gardens without negative effects on the stream and lake ecosystem? Can better access to the area be managed without negative environmental impacts? The evidence obtained in the Sumberjaya research site in Lampung (Sumatra) with various forms of coffee gardens suggests that this is indeed possible – be it with precautions. The options for meeting the village request for support for better access should be explored – if they can guarantee to monitor and guard the water quality in the stream, a substantive 'reward' mechanism in support of the physical access with a road/track that is of sufficient quality not to have direct erosion effects, may be appropriate.

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Appendix 1. List of Maps collected for Singkarak Basin and the vicinity

No	Map Title	Scale	Year	Published by
1	Peta Rupa Bumi Indonesia Lembar Batusangkar	1 : 50000	1984	Bakosurtanal
2	Peta Topografi DITTOP TNI AD Lembar Lubukalung	1 : 50000	1984	DITTOP TNI AD
3	Peta Topografi DITTOP TNI AD Lembar Bukittinggi	1 : 50000	1998	DITTOP TNI AD
3	Peta Topografi DITTOP TNI AD Lembar Airbatumbuk	1 : 50000	1985	DITTOP TNI AD
4	Peta Topografi DITTOP TNI AD Lembar Talawi	1 : 50000	1984	DITTOP TNI AD
5	Peta Topografi DITTOP TNI AD Lembar Solok	1 : 50000	1984	DITTOP TNI AD
6	Peta Topografi DITTOP TNI AD Lembar Padang	1 : 50000	1998	DITTOP TNI AD
7	Peta Topografi DITTOP TNI AD Lembar Alahanpanjang	1 : 50000	1985	DITTOP TNI AD
8	Peta Penggunaan Lahan dan Status Lahan Lembar Solok	1 : 250000	1988	Bakosurtanal
9	Peta Penggunaan Lahan dan Status Lahan Lembar Padang	1 : 250000	1988	Bakosurtanal
10	Peta Sistem Lahan dan Kesesuaian Lahan Lembar Solok	1 : 250000	1988	Bakosurtanal
11	Peta Sistem Lahan dan Kesesuaian Lahan Lembar Rengat	1 : 250000	1988	Bakosurtanal
12	Peta Lahan Kritis pada DAS Singkarak	1 : 100000	-	-
13	Peta Batas DAS/Sub DAS dan Administrasi	1 : 100000	-	Departemen Kehutanan (SBRLKT Agam Kuantan)

14	Peta Pemaduserasian TGHK - RTRWP Sumatera Barat	-	200 2	Bappeda Sumatera Barat
15	Peta Inventarisasi Irigasi Kabupaten Tanah Datar	1 : 200000	-	Dinas PU Pengairan Batu Sangkar, Sum-Bar
16	Peta Penggunaan Tanah Sumatera Barat	-	200 0	Bappeda Sumatera Barat
17	Peta Pemaduserasian TGHK - RTRWP Kawasan Andalan Solok dsk	-	-	
18	Peta Rencana Arahan Penggunaan Lahan Tahun 2003 - 2013	-	200 3	Dinas Kimpraswil Kab. Tanah Datar
19	Peta Tematik Arahan Fungsi Kawasan Daerah Tangkapan Air Singkarak	1 : 100000	-	Departemen Kehutanan (SBRLKT Agam Kuantan)
20	Peta Tematik Alternatif Kegiatan Lahan Pengembangan	1 : 100000	-	Departemen Kehutanan (SBRLKT Agam Kuantan)
21	Peta Penggunaan Lahan dan Pengembangan Daerah Sumatera Barat Lembar Lubuk Sikaping	1 : 250000	199 7	Dept. Transmigrasi dan Pemukiman Perambah Hutan
22	Peta Penggunaan Lahan dan Pengembangan Daerah Sumatera Barat Lembar Padang	1 : 250000	199 7	Dept. Transmigrasi dan Pemukiman Perambah Hutan
23	Peta Penggunaan Lahan dan Pengembangan Daerah Riau Lembar Rengat	1 : 250000	199 7	Dept. Transmigrasi dan Pemukiman Perambah Hutan
24	Peta Penggunaan Lahan dan Pengembangan Daerah Riau Lembar Teluk Kuantan	1 : 250000	199 7	Dept. Transmigrasi dan Pemukiman Perambah Hutan

Appendix 1.(contd) List of Maps collected for Singkarak Basin and the vicinity

No	Map Title	Scale	Year	Published by
25	Peta Penggunaan Lahan dan Pengembangan Daerah Riau Lembar Dabo	1 : 250000	1997	Dept. Transmigrasi dan Pemukiman Perambah Hutan
26	Peta Hasil Kegiatan Identifikasi Permasalahan Penggunaan Lahan Kawasan Hutan TGHK di Kabupaten Solok Sum - Bar	1 : 100000	1990	Sub Balai Inventarisasi dan Perpetaan Hutan Bukittinggi
27	Peta Ikhtisar Topografi DITTOP TNI AD Lembar Solok	1 : 250000	1976	DITTOP TNI AD
28	Peta Rupa Bumi Indonesia Lembar Padang	1 : 250000	1986	Bakosurtanal
29	Peta Rupa Bumi Indonesia Lembar Painan	1 : 250000	1986	Bakosurtanal
30	Peta Rupa Bumi Indonesia Lembar Rengat	1 : 250000	1986	Bakosurtanal
31	Peta Rupa Bumi Indonesia Lembar Dabo	1 : 250000	1986	Bakosurtanal
32	Peta Satuan Lahan dan Tanah Lembar Solok	1 : 250000	1990	Pusat Penelitian Tanah dan Agroklimat
33	Peta Satuan Lahan dan Tanah Lembar Padang	1 : 250000	1990	Pusat Penelitian Tanah dan Agroklimat
34	Peta Sistem Lahan dan Kesesuaian Lahan Lembar Padang	1 : 250000	1988	Bakosurtanal
35	Peta Geologi Lembar Solok	1 : 25000	1995	Pusat Penelitian dan Pengembangan Geologi
36	Peta Geologi Lembar Padang	1 : 25000	1996	Pusat Penelitian dan Pengembangan Geologi

Appendix 4. Land cover Area Summary for *Nagaris* in Singkarak Basin

No	Land Cover Type	Land cover Proportion (hectares)										
		Agricultural fields	Forest	Mixed garden (coconut)	Mixed garden	Pine	Rice field	Shrub	Grass	No data	Others	Total
1	Air Angat	60.3	0	0	3.6	0	61.8	0	0.5	422.9	124.3	**126.2**
2	Andalas	7.1	110.4	164.2	129.9	23.1	76.4	34.8	0	193	45.2	**545.9**
3	Aripan	1063.4	0.4	39.8	651.6	0	143.5	23.7	0	0	249.1	**1922.4**
4	Balai Sabu	22.4	316.2	8.3	243.9	0	112.2	72.1	0	175.9	87.7	**775.1**
5	Batipuh Atas	42.5	0.1	149.4	31	0	346.5	0	0	0	17.2	**569.5**
6	Batipuh Baruh	262.7	2470.6	7.9	102.4	150.8	991.3	110.5	4.1	0	170.1	**4100.3**
7	Batu Tebal	259.5	0	326.8	248.5		76.4	18.7	10	0	139.7	**939.9**
8	Bukit Surungan	500.4	250.5	0	10	28.9	402.3	76.2	0	0	374.3	**1268.3**
9	Bukit Tandang	179.7	0	378.5	362.5	0	154.3	0	0	208.9	214.8	**1075**
10	Bunga Tanjung	234.9	8.5	0	640.6	14	213.8	0	0	0	22.3	**1111.8**
11	Gantung Ciri	75.4			104.3	0	30.8	0	0	0	19.8	**210.5**
12	Gawang	115.5	31.2	127.1	225.5	0	336.5	0	0	347.9	265.3	**835.8**
13	Guguk Malalo	437.6	5780.4	410.4	786.3	109.9	200.1	187.1	83.3	17.3	203.1	**7995.1**
14	Guguk Saral	297.1	550.5	9.4	316.1		40.2	0	0	251.9	37.3	**1213.3**
15	Gunung	70	486.8	0	0	21.3	0	40.1	0	0	0.1	**618.2**
16	Gunung Rajo	265.2	13.9	0	102.3	0	42.2	0	34.6	0	47.7	**458.2**
17	Jao	185.6	130.7	0	8.8	0	131.7	0	0	0	0	**456.8**
18	Kacang	164.7	0	317.5	851.1	0	129.1	80.9	69.5	67.2	33.8	**1612.8**
19	Koto Baru	544.3	0	0	280.1	0	1382	0	0	212.8	0	**2206.4**
20	Koto Ilalang	733.2	752.1	136.2	249.6	0	340	17.8	54.1	941.8	192.8	**2283**
21	Koto Lawas	435.3	102.7	0	16.8	0	121.2	32.8	53.4	183.5	214.1	**762.2**
22	Koto Sani	1537.8	248.5	53	1671.3	0	798.1	62.5	136.9	1174.3	366.5	**4508.1**
23	Muara Panas	97.4	0	0	467.9	0	179.8	0	27.2	0	26.1	**772.3**
24	Muara Pingai	166.4	201.1	3.7	125.6	9.9	165.8	181.1	331.7	770.5	46.5	**1185.3**
25	Padang Lawas	404.4	1443.7	164.2	102.9	3.3	151.6	19.6	19.7	0	9.7	**2309.4**

Appendix 4. (contd) Land cover Area Summary for *Nagaris* in Singkarak Basin

No	Land Cover Type	Land cover Proportion (hectares)										
		Agricultural fields	**Forest**	**Mixed garden (coconut)**	**Mixed garden**	**Pine**	**Rice field**	**Shrub**	**Grass**	**No data**	**Others**	**Total**
26	Panijauan	830.1	55.5	0.8	1274.3	0	85.2	147.1	52.1	27.8	374.5	**2445.1**
27	Paninggahan	295.2	3638.3	64.9	393.5	525.3	258.5	561.6	414.7	1155.4	177.4	**6152**
28	Paninjauan	296.8	2.4	156.7	57.6	9	348.7	9.9	0	386.3	359.9	**881.1**
29	Panyai Ayan	84.5	0	0	0	0	143.6	0	33.8	8.3	373.4	**261.9**
30	Panyakaian	626.4	567.4	0	699.8	0	266.2	0	0	82	411.1	**2159.8**
31	Pitalah	57.2	0	0	95.9	0	341.6	0	1.9	0	39.4	**496.6**
32	Sahapiawsas	55.3	334.4	28.7	157.1	0	126.5	0	0	15.5	105.3	**702**
33	Saning Bakar	599.8	720	438.7	736.7	73.7	346.8	137.9	403.9	3319.3	211.8	**3457.5**
34	Selayo	519.3	0	33.2	201	0	379.4	0	11.8	208	176.9	**1144.7**
35	Simawang	783.3	9.8	66.2	637.4	0	369.2	443.6	115.2	0	183.4	**2424.7**
36	Singkarak	4.6	0	288	92.3	0	150.7	0	0	0	161.6	**535.6**
37	Solok	1001	34.1	137.2	485	0	570.6	0	13	46.4	880.5	**2240.9**
38	Sumani	245.7	0	0	21.7	0	476	0	0	0	283.3	**743.4**
39	Sumpur	271	219.9	0	48	15	72.2	0	30.4	0	8.9	**656.5**
40	Sungai Jambu	358.6	229.2	64.6	47.5	0	94.6	44.8	0	36.3	83.4	**839.3**
41	Tanjung Alai	28.5	0	0	123	0	56.5	0	107.9	0	5	**315.9**
42	Tanjung Barulak	98.1	0	0	554.4	0	169.6	5.1	76.5	0	0	**903.7**
43	Tikalak	21.8	55.9	134.3	266.6	0	123.5	0	7	43.1	48	**609.1**
44	Timbangan	139.4	1939.9	0	53.4	456.6	200.1	100.4	0	0	55.9	**2889.8**

Appendix 5. Land cover Area Summary for Sub catchments in Singkarak Basin

No	CLASSNAME	Land cover Proportion per Sub Catchment in Singkarak Basin													
		1		2		3		4		5		6		7	
		Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%
1	Agricultural fields	2756.6	17.3	729.8	7.3	3319.2	23.9	4017.0	32.8	308.8	8.8	1244.3	22.5	788.6	13.1
2	Forest	895.8	5.6	175.9	1.8	3032.5	21.8	1227.2	10.0	55.0	1.6	161.0	2.9	403.1	6.7
3	Grass	68.8	0.4	21.9	0.2	106.2	0.8	107.4	0.9	15.8	0.5	71.6	1.3	622.9	10.4
4	Mix garden	840.5	5.3	1672.7	16.8	1162.4	8.4	1994.5	16.3	1424.0	40.7	1209.6	21.9	997.8	16.6
5	Mix garden (coconut)	285.0	1.8	968.7	9.7	1075.5	7.7	411.6	3.4	726.2	20.8	31.7	0.6	261.6	4.4
6	Pine	0.0	0.0	0.0	0.0	43.8	0.3	0.0	0.0	0.0	0.0	0.0	0.0	13.7	0.2
7	Ricefield	5459.9	34.3	3349.3	33.7	2588.2	18.6	1451.2	11.8	551.1	15.7	1167.8	21.2	489.9	8.2
8	Settlement	1703.7	10.7	2206.0	22.2	1079.7	7.8	1499.1	12.2	288.8	8.3	537.2	9.7	210.8	3.5
9	Shrub	105.1	0.7	0.0	0.0	68.3	0.5	48.1	0.4	17.6	0.5	21.2	0.4	64.0	1.1
10	Water body	1074.6	6.8	0.0	0.0	0.0	0.0	0.0	0.0	30.8	0.9	2.6	0.0	3.6	0.1
11	No Data (cloud, shadow)	2724.2	17.1	812.5	8.2	1433.4	10.3	1495.4	12.2	81.6	2.3	1071.7	19.4	2152.2	35.8
	TOTAL	**15914.1**	**100.0**	**9936.6**	**100.0**	**13909.2**	**100.0**	**12251.5**	**100.0**	**3499.5**	**100.0**	**5518.8**	**100.0**	**6008.2**	**100.0**

Appendix 5.(contd) Land cover Area Summary for Sub catchments in Singkarak Basin

No	CLASSNAME	Land cover Proportion per Sub Catchment in Singkarak Basin									
		8		9		10		11		12	
		Ha	%	Ha	%	Ha	%	Ha	%	Ha	%
1	Agricultural fields	540.6	4.5	924.4	17.0	40.1	0.9	1673.7	17.0	683.7	19.4
2	Forest	4278.0	35.7	2187.9	40.1	3441.8	76.1	1382.6	14.0	2.0	0.1
3	Grass	595.9	5.0	87.3	1.6	0.0	0.0	42.0	0.4	116.7	3.3
4	Mix garden	738.3	6.2	884.4	16.2	53.5	1.2	912.2	9.3	1354.7	38.4
5	Mix garden (coconut)	278.5	2.3	544.1	10.0	0.0	0.0	484.8	4.9	325.1	9.2
6	Pine	666.3	5.6	36.7	0.7	559.8	12.4	87.8	0.9	33.9	1.0
7	Ricefield	414.0	3.5	417.7	7.7	199.7	4.4	2807.9	28.5	740.8	21.0
8	Settlement	270.7	2.3	168.4	3.1	50.1	1.1	1115.3	11.3	201.0	5.7
9	Shrub	848.7	7.1	161.3	3.0	176.7	3.9	159.4	1.6	10.7	0.3
10	Water body	0.4	0.0	13.3	0.2	0.0	0.0	0.0	0.0	56.9	1.6
11	No data (cloud, shadow)	3358.8	28.0	26.2	0.5	0.0	0.0	1195.9	12.1	1.1	0.0
	TOTAL	**11990.3**	**100.0**	**5451.7**	**100.0**	**4521.7**	**100.0**	**9861.6**	**100.0**	**3526.5**	**100.0**

Appendix 6 : Geology per subcatchment

Subcatchment ID	Geology code	Geological Description	Geology area (ha)	Subc. Area (ha)	% geology / subcatchment
1	Qf	Alluvium, of andesite vulcanic	6149.006		46.83%
1	Qatg	Breccia andesit of Talang	6982.623	13131.629	53.17%
2	Qf	Alluvium, of andesite vulcanic	2013.953		20.36%
2	Qatg	Breccia andesit of Talang	2933.357		29.66%
2	Qtau	Lahar, colluvial deposit	721.53		7.30%
2	Ta	Lava, andesite to basalt	750.192		7.59%
2	Qal	River Alluvium	2037.873		20.61%
2	Trts	Slate, shale part of Tuhur form	1432.554	9889.459	14.49%
3	Qf	Alluvium, of andesite vulcanic	4126.709		29.82%
3	Qatg	Breccia andesit of Talang	1944.425		14.05%
3	Qtau	Lahar, colluvial deposit	7121.447		51.46%
3	Qal	River Alluvium	98.22		0.71%
3	QTwt	Welded tuff, quartz	547.337	13838.138	3.96%
4	Qf	Alluvium, of andesite vulcanic	1380.03		11.32%
4	g	Granite	118.695		0.97%
4	Qtau	Lahar, colluvial deposit	9008.172		73.90%
4	Qal	River Alluvium	1621.435		13.30%
4	Trts	Slate, shale part of Tuhur form	60.811	12189.143	0.50%
5	Qtau	Lahar, colluvial deposit	3054.997		55.65%
5	Qal	River Alluvium	423.008		7.70%
6	Qtau	Lahar, colluvial deposit	3990.272		72.68%
6	Qal	River Alluvium	1499.794	5490.066	27.32%
7	Qtau	Lahar, colluvial deposit	4574.702		77.15%
7	Pckl	Limestone, part of Kuantan form	354.479		5.98%
7	Pl	Permian Limestone	383.514		6.47%
7	Qal	River Alluvium	402.802		6.79%
7	Trts	Slate, shale part of Tuhur form	213.986	5929.483	3.61%
8	Tmgr	Granite, quartz	1541.484		12.95%
8	Qtau	Lahar, colluvial deposit	2968.78		24.94%

			2		
8	Pl	Permian Limestone	6437.699		54.07%
8	Qal	River Alluvium	958.003	11905.968	8.05%
9	Qtau	Lahar	2845.171		53.52%
9	Pl	Permian Limestone	1674.919		31.51%
9	Qal	River Alluvium	795.747	5315.837	14.97%
10	Qama	Breccia andesit of Merapi	11.428		0.25%
10	Qtau	Lahar	1185.369		26.37%
10	Pl	Permian Limestone	2320.181		51.61%
10	Ps	Permian Metamorphic	581.45		12.93%
10	Pq	Quarts of Permian Limestone	397.067	4495.495	8.83%
11	Kub	Basalt, diabase	59.564		0.61%
11	Qama	Breccia andesit of Merapi	8188.279		83.51%
11	Qtau	Lahar	870.715		8.88%
11	Pl	Permian Limestone	468.297		4.78%
11	Ps	Permian Metamorphic	184.755		1.88%
11	Qal	River Alluvium	33.553	9805.163	0.34%

Appendix 6 (contd) : Geology per subcatchment

Subcatchment ID	Geology code	Geological Description	Geology area (ha)	Subc. Area (ha)	% geology / subcatchment
12	d	Basalt	121.363		3.52%
12	Kub	Basalt, diabase	100.215		2.90%
12	Qama	Breccia andesit of Merapi	668.316		19.36%
12	g	Granite	712.522		20.64%
12	Qtau	Lahar	168.384		4.88%
12	Pl	Permian Limestone	15.878		0.46%
12	Ps	Permian Metamorphic	623.516		18.06%
12	Pcks	Phylite, part of Kuantan form	210.594		6.10%
12	Qal	River Alluvium	831.018	3451.806	24.07%

Appendix 7: Time table of activities of the spatial analysis activities

No.	Activites	May'04				June'04				July'04				August'04				Outputs
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
1	**Base Maps Provision**																	Digital boundaries maps; analog Topographic maps
	a. Acquisition of analog maps (administrative, topographic)	■	■	■	■	■	■											
	b. Map digitizing									■	■							
	c. Vector editing										■	■						
	d. Finalizing map												■	■				
2	**Digital elevation model (DEM) Production**																	DEM of Singkarak Basin and the vicinity
	a. SRTM data acquisition	■																
	b. Image preparation (importing and geocoding)	■																
	c. DEM editing		■	■														
	d. Finalizing DEM				■													
3	**Hydrologic Feature Extraction**																	Topographic and hydrologic attributes in Singkarak Basin
	a. Slopes									■								
	b. Subcatchments and drainage Features									■	■							
	c. Routing distance extraction										■	■						
4	**Land cover Mapping**																	Land cover map of Singkarak Basin and the vicinity
	a. Satellite image purchasing				■	■	■											
	b. Geometric correction					■	■	■										
	c. Object-based image classification								■	■	■	■						
	d. Ground truthing												■					
	e. Finalizing land cover map													■				

	f. Accuracy assessment												■				
	g. Information extraction from land cover map												■				
5	**Thematic Maps Provision**																	Digital maps of Geology and Soils
	a. Acquisition of soil and geology maps	■	■															
	b. Map digitizing							■	■									
	c. Vector editing									■	■							
	d. Finalizing map											■	■					
6	**Analyses and report writing**														■	■	■	Report of geospatial Processing and Analyses

Note: Three sub-teams were involved , allowing simultaneous work to do the activities
Sub team A: Activities 1 & 5
Sub team B: Activities 2 & 3
Sub team C: Activity 4