

## PART 2

# KEY MESSAGES: NATURAL DISASTERS AND AGRICULTURAL PRODUCTION, NUMBERS, MODELS, MEASURES, AND CURRENT POLICIES

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Pedro Chambel Leitao and colleagues present a variety of models synthesising knowledge on the interaction between plants, soil, and the atmosphere. This allows for more sophisticated soil and water management during periods of droughts and floods. Farmers and stakeholders should be empowered to assess climate and disaster risks by themselves. A challenge is to control a spatial and time-distributed high variability of properties in soil, atmosphere, and plants and the related data handling. Leitao's development team aims to establish a system of climate scenario management with easy-to-use tools.

Chris Renschler and colleagues present a method to quantify impacts of climate and land use changes on soil and water management in close relationship to community resilience and sustainable development of agricultural watersheds. The PEOPLES resilience framework they present is better suited to counter natural disasters, with its subsystems, demographics, lifestyles, infrastructure, ecosystem services, governmental services, market mechanisms, and disaster response. Each of the subsystems is an individual subject for improvements and optimisation. An entirely managed system can widely abate adverse impacts. In total, the effects and damage after a disaster can be widely minimised.

Eirik Romstad informs on the choice of policy instruments and the correlated impacts on land use and the food industry. Poverty and poorly developed political institutions are key obstacles in dealing with the negative impacts of natural disasters. Well-functioning and integrated food markets are the most important institutions for ensuring the supply of enough food under natural disasters. Crop insurance is the most important single measure to reduce the negative impacts natural disasters have on farmers while futures markets serve the same role for the food processing industry. Price support will increase commodity production volumes particularly in good years, which will lower prices but increase price variability.

# Chapter 4

## Modelling Yield, Natural Resource, and Monetary Losses of Flood and Drought Disasters

Pedro Chambel-Leitão et al.

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# MODELLING YIELD, NATURAL RESOURCE, AND MONETARY LOSSES OF FLOOD AND DROUGHT DISASTERS

**Pedro Chambel-Leitão, Adelio Silva,  
Pedro Galvão, Ana Oliveira**

Hidromod, Portugal

**Tiago Domingos, Ramiro Neves, Tiago Ramos,  
Lucian Simionesei**

Universidade de Lisboa, Portugal

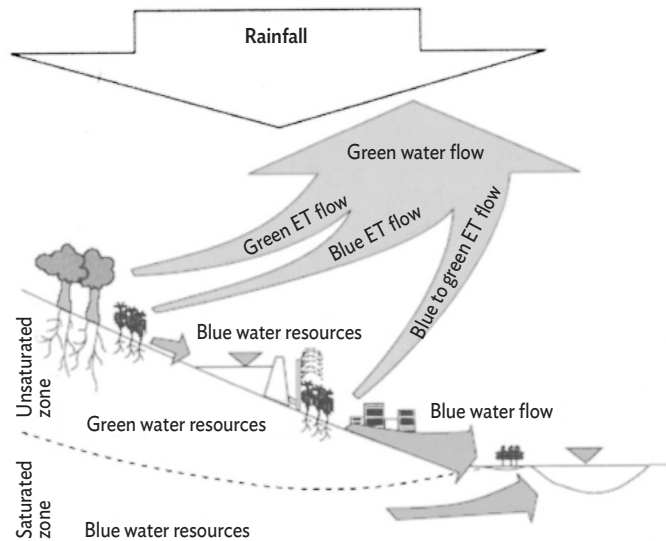
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## Introduction

The world is experiencing changing patterns of water use as a result of changes in land use. The occupation of natural landscapes by agriculture is a major cause in developing countries while changes in crops are being encountered by developed countries. In both cases, economic reasons pushed by the globalisation of world trade play an important role. Also, in both cases, further global changes are expected as a result of climate change. Water availability is essential for socio-economic activities, and citizens expect catchment managers to take the necessary measures to assure quantity and quality for direct and indirect human consumption. Kaufman (2012) considers the possible transformation of water into a commodity. The worldwide water budget can become a measure of the prosperity of a country whereas evapotranspiration can be considered an expense. Knowledge of the processes determining water fate, actual reserves, and the capacity to forecast water consumption are essential for a catchment manager's decision-making. Other authors have named evapotranspiration as green water flow (Falkenmark and Rockström, 2006). These authors associate green water flow with biomass production, which is paramount for food production (Figure 1). The proportion of undernourished people is 12.9% in 2014–2016, and the reduction of this is the first millennium development goal (UN, 2015). To obtain this goal, changes to the green water flow might have to happen. The green water flow has two major components: transpiration, which is a productive flow, and a non-productive evaporative flow from

soil, ponded water (example: rice), and water intercepted from foliage surfaces. Green water is mostly stored in unsaturated zone. However, part of it could also be stored in saturated region due to capillary rise or deep root plants. Remaining stored water is blue water stored in aquifers, reservoirs, lakes, and streams. Blue water flows into the ocean or evaporates to the atmosphere.

**Figure 1: Conceptualisation of Green-Blue Water in the Context of Water-resource Planning and Management**



ET = evapotranspiration.

Source: Falkenmark and Rockström, 2006.

Based on the available data and the simulation models (catchment and reservoir), it is possible to get an early view of the possible evolution of the reservoir and then act accordingly. This way, it is possible to simulate in real time the potential effects of a decision that involves the modification of soil use (erosion, nutrient sources, etc.) or the possible effects of different outflow of reservoir management, specially in what concerns droughts and floods. An example using the Soil and Water Assessment Tool (SWAT) model is the estimation of pollutant loads in the Ardila watershed (Durão et al., 2012). Models provide forecasts and alternative management scenarios based on technical and scientific information of land use, soil type, weather, etc. In other words, the hydrologic models allow the customisation of each solution's specificities, allowing the connection between drivers and pressures (agriculture practices, climate changes, etc.) and the state of the water. Some examples include the use of watershed models with hydrodynamic

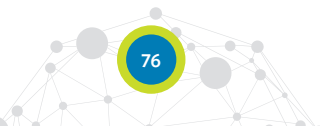
models aimed at integrated coastal water management (Campuzano et al., 2013). Many hydrologic studies have been successful at the hydrographic region scale. In Portugal, where the management plans of the hydrographic region have been concluded, the Alentejo and Algarve plans used SWAT for the catchment water budget and to estimate the diffuse sources of pollution, in particular, from agriculture (Leitão et al., 2012). This approach was possible due to the availability of extensive data in the national water web portal of Sistema Nacional de Informação de Recursos Hídricos (SNIRH). Also, the existence of national-scale weather forecast models allows the implementation of water budget forecasts at the catchment level. Several watersheds in Portugal are shared with Spain, where data are not publicly available and thus makes the task of implementing and calibrating the models more difficult.

Catchment models require field data for validation and for the specification of parameters and boundary conditions. Satellite data are inexpensive and regularly collected at the catchment scale. Together with in situ point data, they can supply model data needs. The combination of these three sources of data provides a continuous spatial-temporal description of the water path and water quality that allows the forecasting capacity required by managers and optimises the cost–benefit ratio. A good example on the use of satellite data to support modelling was the MyWater FP7 project (Hartanto et al., 2015). After implementation and calibration, the model can be used to study processes and assess scenarios, and can also be run operationally to generate daily forecasts based on meteorological forecasts. This model can be validated by comparing the model solution with satellite images, whenever they are available, and can generate the data required by catchment managers to assess water availability and water requirements.

The main problems that can be addressed by these types of models are water availability in the soil for agriculture and in reservoirs for water managers, and flood dynamics for civil authorities and urban managers. One of the main challenges today is communicating to water managers uncertainty in hydro-meteorological forecasts (Ramos et al., 2010). This uncertainty can be estimated in operational systems like the ones proposed by Chambel-Leitão et al. (2016).

## Methodology

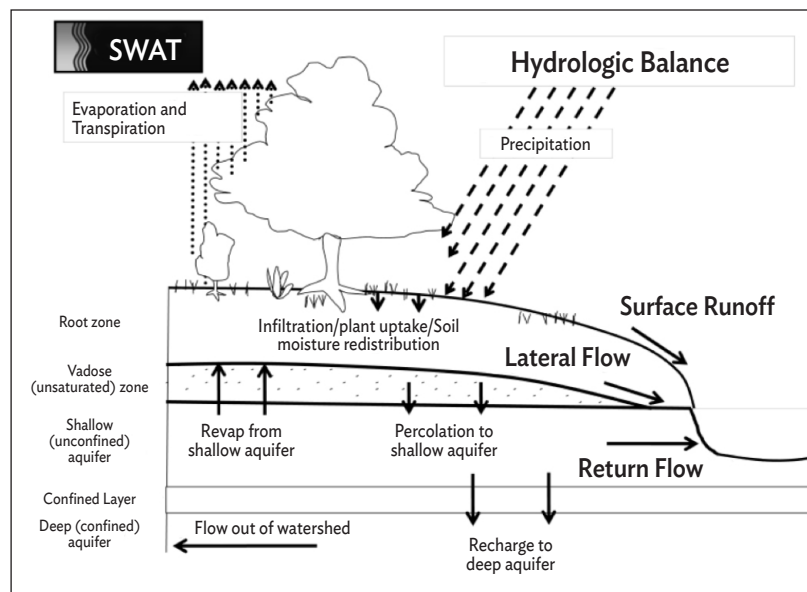
The two models presented here are being used in Portugal (and around the world) to support water managers on flood, drought, and yield estimations, and are the ones used for the results presented below. Also shown are some examples of water information systems used by water managers.



## SWAT Model

SWAT is a river basin or watershed scale model developed by the USDA Agricultural Research Service to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds with varying soils, land use, and management conditions over long periods of time. Intended to be a model for evaluating the impact of agricultural practices at the watershed scale, it came at a time when there was a need to improve water quality. As point sources were getting more controlled, diffuse sources were set as new targets for improvements. In order to do that, the origins of the diffuse sources had to be understood using the scarce data available. Hydrology in the watershed is the main driver for the transport of nutrients. SWAT requires specific information about weather, soil properties, topography, vegetation, and land management practices occurring in the watershed. The physical processes associated with water movement, sediment movement, crop growth, nutrient cycling, etc. are directly modelled by SWAT using this input data.

**Figure 2: Water Budget Fluxes at Hydrologic Response Units**



Source: SWAT course slides.

In SWAT, the simulated basin is divided into several sub-basins. Each sub-basin can either be divided into many hydrologic response units (HRU) with the same land use and soil type, or there can be only one HRU. Each HRU has soil surface as superior boundary and aquifer as inferior boundary. It receives precipitation (PRECIP) from the superior boundary, part of which is converted into runoff (SURQ\_CNT) and another part is infiltrated. The part that is converted into runoff is directed to the sub-basin channel

while the parcel that infiltrates – being able to evapotranspirate (ET) – is carried along the soil profile to be percolated to the aquifer or carried laterally along the soil profile until it reaches the channel (LATQ), or it can be stored in the soil ( $\Delta S$ ). The water that reaches the aquifer is lost to the stream ( $GW_Q$ ), to the deep aquifer ( $DA_{RCHG}$ ), or finally, to the atmosphere (REVAP). REVAP is in fact an indirect way of simulating capillary rise, because the SWAT soil module can only distribute water in the soil profile with a downwards flux.

The equation below summarises the water budget for each HRU:

$$PRECIP = ET + DA_{RCHG} + REVAP + LATQ + GW_Q + SURQ_{CNT} + \Delta S \quad 1$$

SWAT fluxes can also relate with the green and blue water flow mentioned:

$$GreenWaterFlow = ET + REVAP \quad 2$$

$$BlueWaterFlow = LATQ + GW_Q + SURQ_{CNT} + DA_{RCHG} \quad 3$$

### MOHID LAND Model

MOHID Land is a newer model compared to SWAT. It started being developed in 2000 (Neves et al., 2000), reusing the code that was written for MOHID Water (Miranda et al., 2000). This model has some similarities with SWAT. For example, it enables a wide range of spatial and temporal scales, allowing the simulation of a 1 sq m plot or a 5,000 sq km watershed with time steps that can range from seconds to hours. The modular design of MOHID Land facilitates the integration of other models (Miranda et al., 2000). Different water quality modules are available for stream water. Furthermore, this approach minimises the maintenance costs and allows the development of integrated models of soil water flow and surface water flow.

**Table 1: Comparison Between MOHID Land and SWAT Characteristics and Features**

Model	MOHID Land	SWAT
Suited Applications	Wide range of spatial and temporal scales; modular design facilitates integration of other models; advanced capabilities for water quality and water budget analysis	Watersheds; excellent for calculating total maximum daily loads and simulating a wide variety of conservation practices and other best management practices; successfully applied across watersheds in several countries
Main Components	Hydrology, weather, soil properties, crop growth, nutrients, pesticides, agricultural management and channel routing, overland/channel flow, unsaturated/saturated zone, snowmelt; aquifer/rivers exchange, advection/dispersion of solutes, geochemical processes	Hydrology, weather, sedimentation, soil temperature and properties, crop growth, nutrients, pesticides, agricultural management, and channel and reservoir routing
Runoff on Overland	2-D diffusive wave and dynamic wave equations	CN for runoff

Model	MOHID Land	SWAT
Subsurface Flow	3-D groundwater and unsaturated flow	Lateral subsurface flow/ground flow
Chemical Simulation	N, P, pesticides, C, dissolved conservative solutes in surface, soil, and ground waters	N, P, pesticides, C
Spatial Scale	Distributed	Semi-Distributed
Temporal Scale	Event-based; continuous; variable steps	Continuous; daily steps
Watershed Representation	2-D rectangular/square overland grids; 1-D channels; 3-D unsaturated/3-D saturated flow	Sub-basins based on topography, HRU, ponds, groundwater, and main channel
Availability	Public	Public

1-D = one dimensional, 2-D = two dimensional, 3-D = three dimensional, C = carbon, CN = carbon nitrogen, HRU = hydrologic response unit, N = nitrogen, P = phosphorus, SWAT = Soil and Water Assessment Tool.

Source: Authors.

## Water Information Systems

Platforms that provide hydrologic data are very important to water resources managers. In Portugal and Spain, there are two examples of this type of platform: the National Information System of Water Resources (Sistema Nacional de Informação de Recursos Hídricos) and the Automatic System of Hydrologic Information (Sistema Automático de Información Hidrológica). The main activities of these systems are to measure, transmit, process, and in some cases, validate the data, which allow the characterisation of the state of rivers and some hydraulic structures. In the end, they will be a tool to archive and provide long-term series of hydrological data, which helps in the management of water resources and in the prediction and monitoring of extreme climatic events such as floods and droughts. The SNIRH system was implemented with the goal of facilitating the usage of collected data in different studies and objectives (Santos et al., 1997).

In Portugal, SNIRH was used to develop a system of flood monitoring and alert (Sistema de Vigilância e Alerta de Cheias) (Lacerda et al., 1997). Later, this system was updated with new features (Rodrigues et al., 2003), becoming the system of water resources monitoring and alert of Portugal (Sistema de Vigilância e Alerta de Recursos Hídricos de Portugal). The system is based on flow measurements and water levels measured in reservoirs and provided by National Institute of Water (Instituto Nacional da Água), Energies of Portugal (Energias de Portugal), and other entities that manage these reservoirs. However, this system does not include meteorological forecasting. Other countries, such as Brazil and the US, have similar systems. In Brazil, all hydrological information resulting from monitoring systems is available in the System of Hydrologic Information (Sistema de Informações Hidrológicas) managed by National Water Agency (Agência Nacional das Águas). In the US, the corresponding system is National Water Information System, which supports the acquisition, processing, and storage of hydrological data. Both systems provide real time information, with that of the US having an alert system available to the general public.



Normally, these systems do not include modelling results as an output. On the other hand, multiple measurements of areas are scarce in these systems. The development of models applied to different spatial scales and making them operational is the aim of this paper. For that, some examples are presented on model application to different scales.

## Results

Land use change drives the modification of three interdependent global variables of the watershed: evapotranspired water, biomass production, and organic matter content of soil. Assessing the consequences of land use changes requires the capacity to study those global variables at an integrated level. Catchment models can simulate those interactions together with all the processes that determine plant dynamics, and are major tools not only for integrated studies but also for decision making. Decision makers, however, work at different scales, which sometimes make difficult the dialog to manage overall water recourses. The models presented here have a wide range of spatial and temporal scales. Three examples are provided.

### i) Managing water on farm scale

In the FIGARO FP7 (Flexible and Precision Irrigation Platform to Improve Farm Scale Water Productivity – Seventh Framework Program) project, a system based on AQUASAFE platform was implemented with the objective of providing easy-to-use tools capable of gathering up-to-date data and forecasts that may advise both in what concerns the prevention (scenarios management), the actual risk (how the actual catchment conditions constrain the risk level), and the response (in the present conditions, and the short-term forecasts of what areas are being at risk in the following days). This vision goes beyond the traditional event prevention to response cycle by contributing to long-term land and water bodies management through information-rich support of the relevant stakeholders' decisions on water management towards the effective, continuous water control, and promotion of economic growth. It seeks an integrated forecast system that can simulate hydrologic, hydraulic, and soil plant air models using meteorological measurements and models results as input (Simionesei et al., 2016).

Non-specialised personnel find the AQUASAFE platform easy to use and that it can integrate any type of model and data source. As a result, the system represents an added value in what concerns the information that can be processed and integrated through ICT tools in a user-friendly way.

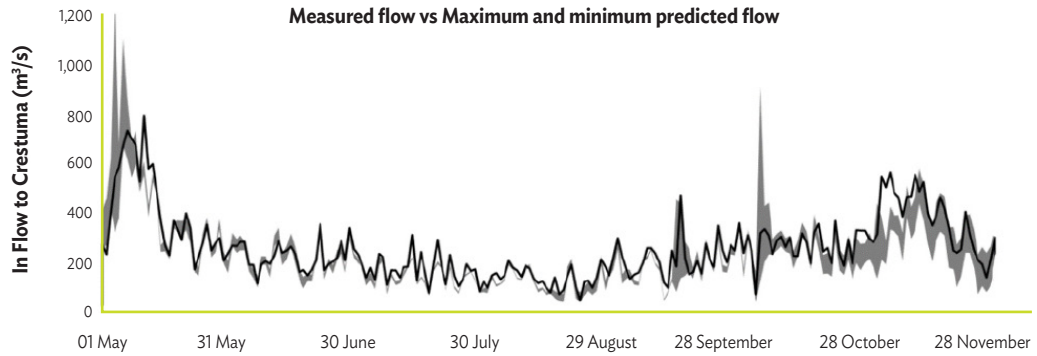
The major beneficiaries of the FIGARO platform include:

- The environment, through overall reduction in use of fresh water for irrigation and the consequent reduction in the water footprint.
- Individual farmers who, by employing the platform, fulfil their obligation to save water in compliance with the growing trend of European regulation compelling the use of managed irrigation.
- The food industry, through companies buying agricultural products grown with the FIGARO Platform. These companies will benefit twice: first, by better compliance with regulation that compels them to lower the environmental impact of their businesses, and second, by promoting themselves as environmentally friendly business by acquiring the 'environmentally friendly farming practices used in our products lowered water footprint' label.
- Policymakers and decision makers, who will gain tools for monitoring and managing agricultural practices including irrigation, fertigation, and use of saline/brackish water. With FIGARO platform, they will be able to manage natural resources such as water and energy more effectively and accurately.
- Consumers of Europe and beyond, who will benefit from healthier and higher quality food products, which have been produced with more sustainable practices, e.g. use of less fertilisers and minimal amount of water.

## ii) Managing water on watershed scale

Hidromod daily provides the Portuguese Electrical Company with predictions on streamflow. This system, known as AquaSafe Douro, is divided into two main components: AquaSafe Server, which stores and allows the manipulation of data generated in the system (model results) or externally (SCADA systems, FTP, Open DAP, etc.), and AquaSafe Desktop Client, which is the user interface (Chamabel-Leitão et al., 2016). The first component lets the user schedule a range of activities such as running models, publishing reports, etc. Communication with this component is made through two web channels: an exchange data channel and an administration channel. AquaSafe Desktop Client is the interface that assures connection between user and server. This platform was designed for 'operational' scenarios, providing a range of features (SIG, graphs, reports, etc.) that can be grouped and accessed in workspaces. Each workspace can be available only for one user or for a group of users. Hydrologic models MOHID Land and SWAT were implemented in this system to provide daily predictions (Figure 3).

**Figure 3:** Comparison of Simulated Flow (Grey Area) and Measured Flow (Black Line)



Source: Authors.

### iii) Managing water at country scale

The perspective of managing not only water but also the potential for Portugal’s biomass production by using SWAT model is the subject of a recent doctoral thesis (Chambel-Leitão, 2016). Watershed-simulated fluxes for Continental Portugal can be divided in blue water flow (Figure 1) and green water flow. Table 2 shows the accumulated volumes of water flow from precipitation, green water, blue water, and the water storage variation on the soil and shallow aquifer. The volumes result from the sum of the period 1 October 1979 to 30 September 2003, while the storage variation takes into consideration the volume available at the beginning and end of this period.

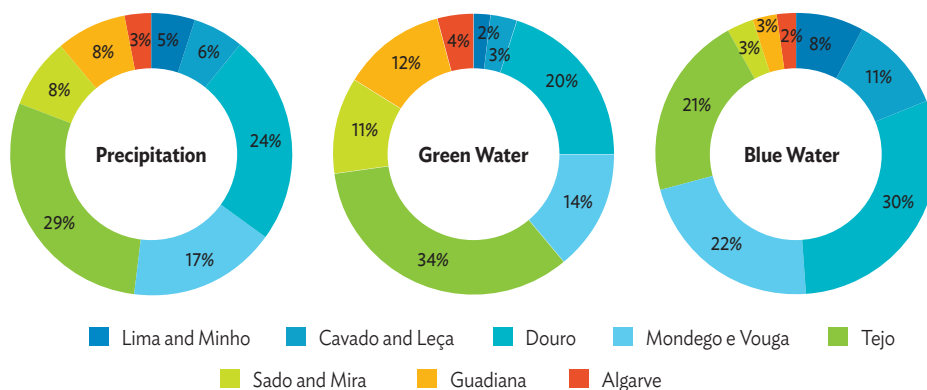
**Table 2:** Water Budget per Portuguese Hydrographical Region from 1 October 1979 to 30 September 2003 for Model Run with IPMA-GRID (values in km<sup>3</sup> in 24 years)

Hydrographical Region	Code	PRECIP	Green Water Flow	Blue Water Flow	ΔS
Lima and Minho	PTRH1	80.45	24.21	56.30	-0.13
Cavado and Leça	PTRH2	111.07	36.67	74.61	-0.27
Douro	PTRH3	411.79	206.67	205.47	-0.78
Mondego e Vouga	PTRH4	292.56	142.80	149.98	-0.75
Tejo	PTRH5	494.37	356.25	138.35	-2.08
Sado and Mira	PTRH6	140.73	118.44	22.45	-0.59
Guadiana	PTRH7	144.85	123.61	21.47	-0.58
Algarve	PTRH8	51.73	41.25	10.54	-0.18

Source: Authors.

Based on the global volumes in Table 2, the proportion of each of HR in each flow can be shown (Figure 4). For example, the area of HR 1, 2, and 3 accounts for only 35% of precipitation, but for 49% of all the blue water flow. The area of HR 6, 7, and 8 accounts for 19% of precipitation but only contributes to 8% of blue water flow.

**Figure 4: Accumulated Volumes of Water Flow from Precipitation, Green Water, Blue Water per Hydrographical Region**



Source: Authors.

## Conclusions

Water managers work at different scales, which sometimes make difficult the dialogue to manage overall water resources. The models presented here have a wide range of spatial and temporal scales. Three examples were presented that show it is possible to use models as integrative tool to help manage water resources. At farm scale, precision farming can allow for a sustainable growth in agricultural production. Modelling is a very helpful tool to support decision-making in precise farming. The FIGARO project is an example of model implementation. Extreme water conditions like flood and drought can result in high monetary losses. These extreme events will tend to be aggravated by expected climate changes. Again, models can help in the development of warning systems to prevent losses. An example of this type of model implementation is presented at watershed scale for Portugal. The development of centralised water information systems is very important. The Portuguese water systems do not include modelling results as an output. On the other hand, data became scarce in recent years on this system. The development of a model to country scale (Portugal) allows the possibility of a country having application that will provide water information to support decisions. AQUASAFE, which has been proven efficient at farm scale and at watershed scale, is then used at country scale.

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