BIOENGINEERING FOR GREEN INFRASTRUCTURE

ADB

ASIAN DEVELOPMENT BANK

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I. Green Infrastructure and Bioengineering

Green infrastructure is a broad term used to describe measures where nature-based solutions form part of the infrastructure. Naumann et al. (2011) provide the following classification:

"Green infrastructure is the network of natural and semi-natural areas, features and green spaces in rural and urban, and terrestrial, freshwater, coastal and marine areas, which together enhance ecosystem health and resilience, contribute to biodiversity conservation and benefit human populations through the maintenance and enhancement of ecosystem services.

Green infrastructure can be strengthened through strategic and co-ordinated initiatives that focus on maintaining, restoring, improving and connecting existing areas and features as well as creating new areas and features."

Bioengineering is a subset of green infrastructure that uses vegetation to serve an engineering function. The most common uses of bioengineering include soil surface protection against erosion, soil stabilization, and improved drainage functions.

While vegetation is widely used for landscaping, the focus of this brief is its use in different forms of infrastructure.

In its Strategy 2030, the Asian Development Bank (ADB) pledged to promote "quality infrastructure investments that are green, sustainable, resilient, and inclusive." The inclusion of bioengineering in an infrastructure project can help ADB fulfill this objective.

II. Purposes of Bioengineering

Functions and Plant Requirements

Bioengineering uses plants to protect soil surfaces and stream banks, and to strengthen shallow soil. It can control erosion and prevent or stabilize shallow slope movements where the depth to failure is no more than 0.5 meter (m). If the depth to the sliding surface of a slope failure is greater than 0.5 m, then bioengineering should only be applied in conjunction with other slope stabilization techniques, typically, retaining walls.

Bioengineering techniques often provide the most cost-effective methods of surface protection for soil slopes, which is achieved through a surface cover of vegetation that armors the surface against erosion.

But soil protection is not bioengineering's sole application. Different types of plants and planting materials produce different rooting patterns, which can bind or anchor the surface layer of soil and increase its resistance to deformation. This prevents, or at least reduces, the incidence of deeper failures, such as large gullies resulting from the formation of shallow rills.

Aboveground, the stems and leaves of plants can slow moving water and trap materials that are being carried by water or gravity. These features account for the range of engineering functions listed in Table 1.

Table 1: Bioengineering Functions

Engineering Functions	Requirements of Plants
Catch eroding material moving down a slope, as a result of gravity alone or with the aid of water. The stems of the vegetation perform this function.	• Strong, numerous, and flexible stems • Ability to recover from damage
Armor slopes against surface erosion from both runoff and rain splash. This requires a continuous cover of low vegetation; plants with high canopies alone do not armor the slope.	• Dense vegetation cover • Low canopy • Small leaves
Reinforce the soil by providing a network of roots that increases the soil's resistance to shear. Reinforcement depends on the form of the roots and the nature of the soil.	• Plants with extensive roots with many bifurcations • Many strong, fibrous roots
Anchor surface material by extending roots through potential failure planes into firmer strata below. If the potential failure is deeper than 0.5 meter, anchoring can be achieved only by large woody plants with big vertical tap roots.	• Plants with deep roots • Strong, long, vertically oriented roots
Support the soil mass by buttressing and arching. Large, heavy vegetation, such as trees, at the base of a slope can provide support in the form of buttresses; or on a micro scale, clumps of grass can buttress small amounts of soil above them. Across the slope, a lateral effect is created in the form of arching: this is where the soil between buttresses is supported from the sides by compression.	• Extensive, deep, and wide-spreading root systems • Many strong, fibrous roots
Reduce the velocity of water or wind movement across the surface of the soil. This is done by the stems of vegetation offering resistance that retards the flow of water or air.	• Strong, numerous, and flexible stems • Many strong, fibrous roots
Drain excess water from slopes. The planting configuration of the vegetation can enhance drainage by channelling runoff down a slope, along erosion-protected lines, thereby avoiding saturation and slumping. Vegetation can also reduce pore-water pressure on the slope by extracting water via the roots and transpiring it out through the leaves.	• Plants small enough to be planted in closely packed lines • Ability to resist scour • Large leaf area to maximize transpiration

Source: Adapted from J. Howell. 1999. Roadside Bio-engineering: Site Handbook. Government of Nepal, Department of Roads: Kathmandu.

Applied Techniques in Southeast Asia

There are many bioengineering methods that can be used in different environments and with specific site requirements. The incorporation of natural elements, however, requires greater care in transferring methods from one place to another, unlike with hard engineering measures.

Table 2 summarizes the main techniques that have been introduced to Southeast Asia and tested in field trials. They provide options for slope protection works in most infrastructure situations.

Civil engineering uses inert materials, such as concrete and steel, that have accurately definable properties. The poor predictability of vegetation growth means that its strength cannot be guaranteed in the same way, and therefore, it has a higher risk threshold. In most cases, the establishment of a full vegetation cover on unconsolidated fill slopes such as embankments can be achieved in one to two wet seasons.

Studies show how stability analysis can be modified to incorporate vegetation, but they generally assume "average" growth. The growth on any site is rarely comparable because numerous environmental factors cannot be assessed readily (soil nutrition and rooting conditions) or are variable (rainfall and temperature).

For these reasons, plant growth remains dependent on factors that cannot be determined with certainty. These shortcomings are counteracted by planting the most robust species available in a locality and by using local knowledge and experience to predict growth characteristics on different sites.

There is no single species or technique that can resolve all slope protection problems. However, once the right plants are established, they can be flexible and robust. They can recover from significant levels of damage from flooding and debris deposition, although their full recovery may not be evident until the following growing season.

Plants reduce water on a slope through evapotranspiration, but they cannot change soil moisture significantly at critical periods of intense and prolonged rainfall when the ground is fully saturated. Grasses form large, dense clumps which provide the most robust slope protection during the monsoon season in tropical areas where rainfall can be intense.

Shrubs (woody plants with multiple stems) and small trees (woody plants with single stems) can be grown from cuttings taken from their branches. Plants propagated by this method tend to produce strong roots that can provide better soil reinforcement than the natural rooting systems developed from seedlings of the same species.

Bioengineering with retaining wall for slope stabilization. A long translational slope failure in the northern region of the Lao People's Democratic Republic is shown before (left) and after (right) it was stabilized predominantly with bioengineering techniques. Brush layers are growing on the backfill above the composite revetment wall, and above these are lines of hand-planted grass. (photos by J. Howell)

Table 2: Bioengineering Techniques Appropriate in Southeast Asia

Technique	What It Offers
Grass planting: Root-shoot slip cuttings of large grasses are planted in lines across a soil slope. Slips are made by splitting out the clumps to give a small section of both roots and shoots. Lines are usually horizontal or diagonal, depending on slope material characteristics.	• The best and quickest way to create a surface vegetation cover on a bare slope with at least 30% soil • Effective cover on almost all soil slopes up to 2V:1H • Robust protection and shallow reinforcement of the surface soil • Grass may also be seeded over bare surfaces, but this frequently loses all engineering functions other than armoring
Direct seeding: The seeds of shrubs and small trees are inserted into crevices in slopes composed of moderately weathered rock.	• The best way to establish vegetation on rocky slopes
Brush layers and fascines: Woody cuttings from shrubs or small trees are laid in different ways on shallow trenches across slopes formed in unconsolidated debris. They can be installed on slopes of up to about 1V:1.25H. Palisades can be on steeper sites, up to about 1.75V:1H.	• Instant physical barrier that interrupts runoff and is stronger than grass • Strong erosion protection and soil reinforcement as the plants take root and grow • Often successful on stony debris • Most shrubs will tolerate some shade, so this method can often be used under tree canopies where grasses will not grow
Truncheon cuttings: Big woody cuttings from trees are inserted upright at intervals on slopes or stream banks formed in deep or poorly stabilized and unconsolidated debris.	• Relatively strong plant material on slopes that are still unstable • Ability to withstand damage from moving debris
Live check dams: Small check dams with structural elements made from the woody cuttings of trees (or bamboo cuttings) are placed at intervals in erosion gullies.	• Low-cost, flexible structures to reduce erosion where water flow is concentrated but ephemeral • Relatively limited disturbance to the slope, particularly on weak, unconsolidated materials
Tree planting: Potted seedlings from a forest nursery are planted at intervals across a soil slope.	• Restoration of a forest mix of trees in the long term • Trees take at least 5 years to contribute significantly to slope strengthening or to establish a complete cover, and initially may be vulnerable to grazing

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Table 2 continued

Technique	What It Offers
Large bamboo planting: A section of the stem and root of large bamboo is planted, usually at the base of a slope, on a stream bank or above a river training wall within the flooding zone. It must be about 2 meters long and excavated from the mother clump carefully.	• Large bamboos support the base of a slope or strengthen riverbanks by providing a very strong line of large plants • Bamboo takes at least 5 years to contribute significantly to slope strengthening, but once they are well established, they form flexible, immovable barriers • With multiple stems, they catch debris moving down the slope
Vegetated stone pitching: Stone pitching is where small rocks are hand-laid to protect a soil slope surface; they can be vegetated by inserting grass slips or woody cuttings between them.	• A very strong surface protection in gully beds or other locations where periodic water flows may occur • Stronger than purely dry-stone pitching but more flexible than mortared pitching
Geotextile coverings: Permeable coverings are spread on the surface and used as an aid to start vegetation growth. These may be of natural fibers, e.g., jute or coir, or synthetic.	• Immediate surface covering to reduce erosion while vegetation gets established, allowing bioengineering to be undertaken on very harsh or very steep slopes • It can be hard to place geotextiles on uneven ground, and specialist supervision is needed • Some synthetic coverings can sterilize the surface if vegetation is not established
Wattle fences: Fences made of woven branches or bamboo are used to retain small volumes of debris, forming mini terraces.	• A rapid temporary measure on slopes with loose surface debris • Limited strength compared with live bioengineering measures
Hydro-seeding: A mixture of seeds, binder, mulch, and fertilizer is sprayed on slope surfaces (various proprietary systems are available). This is a capital-intensive technique, relying on specialist machinery, material, and skills. Unless applied on very large sites, this is more expensive than hand-planted works.	• Rapid surface covering of vegetation over large areas • Seed mixes of locally appropriate species can be difficult to obtain • Adhesion of spray material can be poor on steep roadside cuts under intense tropical rainfall, leading to incomplete coverage • Some systems using thick mulch applications develop a shallow discontinuity in the rooting structure, leading to rapid early plant growth, followed by a sudden decline or shallow mass failure

H = horizontal, V = vertical.

Sources: Scott Wilson Limited. 2008. Slope Maintenance Manual. Department for International Development of the United Kingdom and Government of the Lao People's Democratic Republic; and International Centre for Environmental Management. 2017. Natural Solutions to Erosion Control in Viet Nam: Case Studies from the Northern Mountainous Region. ADB Capacity Development Technical Assistance Project Promoting Climate Resilient Rural Infrastructure in Northern Viet Nam.

III. Benefits of Bioengineering

In bioengineering, natural building materials are incorporated into infrastructure design to increase their

(i) strength over time, for at least 10 years;
(ii) flexibility and capability to absorb ground movement and energy from water and wind; and
(iii) ability to recover from damage.

Environment and Society

Beyond serving standard engineering functions, bioengineering also has environmental benefits that tend to be significant locally but may have a wider impact globally:

(i) absorption of noise from factories, roads, quarries, and mines;
(ii) reduction in dust emissions from gravel roads, mines, and quarries;
(iii) reduction of surface runoff through increased interception and infiltration of rainfall;
(iv) sequestration (capture and storage) of atmospheric carbon;
(v) shading and acting as a windbreak;
(vi) providing a visible line of significance on roads in poor visibility; and
(vii) improvement of the visual appearance of the landscape.

Bioengineering should be seen as part of sustainable asset design and management as it uses low-cost building techniques and materials. It is advantageous in rural areas or parts of cities with large, low-skilled populations because the techniques are simple. Since bioengineering is labor-intensive, its use creates jobs for nearby communities. Following construction, local residents can be more involved in the maintenance of bioengineered sites—more than they would in maintaining structures of civil engineering—particularly in rural areas where people are skilled in farming and forestry.

Grass slope protection. In Viet Nam, large grasses are planted to prevent erosion below the toe of a road retaining wall. In Cambodia (right), grass planted on the bend of an irrigation canal is among the different methods of bank stabilization (photos by J. Howell).

Strongly rooted plants. In northern Viet Nam, the method adopted of propagating shrubs and small trees for shallow stabilization of unconsolidated slopes is one that makes the plants produce a mass of fine, strong roots, which provide soil reinforcement. (photos by the International Centre for Environmental Management).

Investment in bioengineering extends the effectiveness of standard civil engineering infrastructure or helps to mitigate its impacts. Thus, even though the primary aim of bioengineering is to create and maintain functioning infrastructure such as irrigation channels, roads, and buildings, its benefits go beyond the construction sites.

Because plants restrict the amount of debris from degrading slopes, they reduce blockage to canals and drains, damage to road pavements and sediment pollution of natural watercourses. Such benefits result in reduced offsite costs: for example, stabilizing road embankments can contribute to the protection of other assets such as houses and agricultural fields.

Plants selected for bioengineering may serve other purposes aside from engineering. Howell (1999) described how plants that were unpalatable to livestock and therefore unlikely to be damaged by foraging could be selected, as well fodder and small timber species in areas with good land management. Increasing interest in non-timber forest products and medicinal plants also promote the use of groundcover plants mixed with overstorey tree crops, which provide root reinforcement that is suitable in certain locations.

Biodiversity is almost always a benefit of bioengineering. Enhanced biodiversity outcomes can be achieved using certain species in the bioengineering mix, or a combination of species to create habitats. Often, it is better to use indigenous species for bioengineering because they are naturally adapted to growth in the site conditions. Such plants are rarely invasive, and their use can favor the establishment of habitats for indigenous fauna.

Because their proliferation is curbed by the ecosystem, indigenous plants do not spread and take over a site, but introduced species can expand and dominate a habitat that is not naturally adapted to their presence. Bioengineering with indigenous species can be designed to develop into plant communities that require little or no maintenance. In contrast, vegetation introduced by bioengineering may require maintenance at a later stage to curtail growth outside the area being treated. Sensitivity to invasiveness and the focus on using indigenous species for revegetation are most pronounced in island ecosystems rather than continental ecosystems, where invasive weeds are often already a problem. However, in some cases, the use of fast-growing exotics may be advantageous if they have been proven to be non-invasive.

Economically valuable species. In the Lao People's Democratic Republic, bioengineering uses economically valuable species, such as Cardamom (left) as an understorey on steep slopes and the chestnut species Castanopsis (right) on a hedge (photos by J. Howell).

Riverbank stabilization. Vetiver grass planted along a riverside in northern Viet Nam (left) and the grassed flood foreshore with small trees on an embankment in Cambodia (right) provide for riverbank stabilization (photos by the International Centre for Environmental Management and J. Howell).

Financial Implications

The cost and benefits of bioengineering are difficult to quantify because of the range of variables involved, and a lack of reliable input cost and monetized output benefit data.

For example, slope-derived rock debris on hill roads is one of the largest contributors to road maintenance costs as it blocks drains and damages pavements, but there are no known calculations of the reduction in maintenance costs as a result of applying bioengineering techniques to prevent the debris from falling on the road.

Similarly, the cost of losses in agricultural productivity due to erosion can be debilitating but demonstrating this at the farm level is difficult. In most cases, the attribution of benefits is hard to achieve without a formal trial with a control (no treatment) element.

The cost of construction using solely bioengineering measures was significantly low compared to the cost of conventional techniques for slope protection using concrete tiles (International Centre for Environmental Management 2017a).

At one site in northern Viet Nam, the cost of bioengineering techniques ranged from 9.5% to 22.8% of their conventional alternatives. This series of trials found that the huge savings came from the protection of the slopes of riverbanks above hard-toe protection works.

The International Centre for Environmental Management (2017a) also emphasized the inclusiveness and wage benefits from bioengineering works, which in the trials included a large proportion of women and ethnic minorities in the labor force.

Netting for bioengineering using local jute. Women spin and weave raw jute to produce netting for bioengineering works in Nepal. Jute netting provides a short-term surface cover while a grass cover is established (photos by J. Clark).

Site Locations and Characteristics

The practical approach is to address the underlying ground stability and drainage first. In many cases, the structural integrity of a slope is already good enough, which means it only requires protection with minor additional physical support. Then, bioengineering measures need to be designed to protect surfaces in ways that enhance the slope's stability and improve drainage works.

Following the completion of earthworks, such as canal bank construction or roadside stabilization measures, soil surfaces are frequently left in a highly erodible condition. To prevent further environmental and engineering damage, they must be protected against erosion as soon as possible.

This is the starting point for bioengineering in most projects, and the work usually involves the establishment of plants in the hostile environment of a construction site, rather than in the more benign site of a cultivated field. Hence, the right techniques, plant species and planting materials must be selected carefully.

The techniques listed in Table 3 are appropriate for use in different sites. This shows how an understanding of the characteristics of a site is crucial to determining the right technique.

It is important that bioengineering works be designed locally. For this reason, the table refers to components of typical sites rather than to whole sites.

The designer should expect to use a range of various techniques on the same site. This is because a "typical site" may consist of, for example, cut slope faces, debris slopes, and a landslide head scarp.

Table 3: Determination of Bioengineering Technique According to Site Characteristics

Site Characteristics	Recommended Techniques
Sites mainly above roads and other infrastructure	
Cut slope in soil, very highly to completely weathered rock or residual soil, at any grade up to 2V:1H	Grass planting in lines, using slip cuttings
Cut slope in colluvial debris, at any grade up to 1V:1H (steeper than this would need a retaining structure)	
Trimmed landslide head scarps in soil, at any grade up to 2V:1H	
Embankment slopes, roadside lower edges or shoulders in soil or mixed debris	
Cut slope in mixed soil and rock, or highly weathered rock, at any grade up to about 4V:1H	Direct seeding of shrubs and trees in crevices
Trimmed landslide head scarps in mixed soil and rock, or highly weathered rock, at any grade up to about 4V:1H	

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Table 3 continued

Site Characteristics	Recommended Techniques
Sites mainly below roads and other infrastructure	
Fill slopes and backfill above walls without a water seepage or drainage problem (should be no steeper than about 1V:1.5H, if possible)	Debris slopes underlain by rock structure, with slope grade between 1V:1H and 1.75V:1H
Debris slopes underlain by rock structure, with slope grade between 1V:1H and 1.75V:1H	Palisades using woody cuttings from shrubs or trees
Other debris-covered slopes where cleaning is not practical, at grades between 1V:1.5H and 1V:1H.	Brush layers using woody cuttings from shrubs or trees
Fill slopes and backfill above retaining walls showing evidence of regular water seepage or poor drainage (should be no steeper than about 1V:1.5H)	Fascines using woody cuttings from shrubs or trees, configured to contribute to slope drainage
Large and less stable fill slopes more than 10 meters from a building or road edge (grade not necessarily important but could in time, settle naturally at about 1V:1.5H or less)	Truncheon cuttings (big woody cuttings from trees)
The base of fill and debris slopes	Large bamboo planting or tree planting using potted seedlings from a nursery
Other bare areas, such as the area above landslide head scars, on large debris heaps and stable fill slopes	Tree planting using potted seedlings from a nursery
Waterflow areas	
Canal, stream and riverbanks where water erosion occurs during floods	Brush layers using woody cuttings from shrubs or trees
Large riverbanks where fast-flowing water erosion occurs during floods	Large bamboo planting
Gullies or seasonal stream channels with occasional minor discharge	Live check dams using woody cuttings of shrubs and trees
Gullies or seasonal stream channels with regular or heavy discharge	Stone pitching, probably vegetated; gabion check dams may also be required

H = horizontal, V = vertical.
Source: Adapted from Scott Wilson Ltd. (2008). Slope Maintenance Manual. Department for International Development of the United Kingdom and Government of the Lao People's Democratic Republic. https://assets.publishing.service.gov.uk/media/57a08bb840f0b64974000d16/Seacap21_Slopemaintenancemanual.pdf.

Selection of Appropriate Plant Species

When selecting a species for bioengineering works, the following factors must be considered:

(i) The plant must be the right type to perform the required bioengineering technique. Some plant categories include (a) grasses that form large clumps, (b) shrubs or small trees that can be grown from woody cuttings, (c) shrubs or small trees that can grow from seeds in rocky sites, (d) trees that can be grown from potted seedlings, form clumps.
(ii) The plant must be capable of growing in the location of the site (climatic conditions).
(iii) There must be enough soil material available for the plant at the site (some pioneer plants require very limited soil).
(iv) The plant must also serve the secondary functions that may be required, such as agriculture or forestry production, biodiversity enhancement, and screening for dust or noise.

Indigenous plants that meet these requirements are always preferred. In some cases, certain types of plants are considered undesirable, such as those that give too much shade and inhibit the growth of other plants, i.e., trees with a dense canopy that stop grass from forming a surface cover, or invasive plants that might become weeds.

Project Preparation

Below is an example of the terms of reference for the work involved in determining and managing bioengineering works as part of a typical project preparation:

(i) The supervising engineer shall acquire the services of a plant ecologist or similar specialist to design suitable bioengineering interventions that will protect and increase the resilience of project infrastructure.
(ii) The ecologist should work with the engineer's staff to identify work sites and determine requirements for appropriate techniques. The resulting plans and designs should aim to provide bioengineering solutions for all bare soil areas on fill and cut slopes, potentially unstable or erosion-prone areas, stream banks, quarry and borrow pit sites, and all other disturbed land requiring rehabilitation.
(iii) The ecologist will identify suitable indigenous plants for use in the application of bioengineering techniques as part of the civil works component of the project. Through consultation with botanists and local rural people, shrub and grass species will be identified that are indigenous, deep-rooting, and non-invasive. For each candidate plant identified, information on propagation methods must be gathered, and plans made for the nursery raising of cuttings or seedlings.
(iv) The ecologist will also work with the engineer's staff to draw up appropriate specifications, quantity estimates, and contract arrangements, and to oversee the implementation and subsequent maintenance of the bioengineering works.

Planning and Implementation

In South Asia and Southeast Asia, bioengineering work should only be undertaken in the first half of the wet season, or between April and June or July. The slope should be moist during planting. If it does not rain within 24 hours of planting, the plants will need to be watered until it rains. Planting should not be done later as there may not be enough time for a plant's roots to develop adequately to survive the subsequent dry season. Before planting can begin, planning and design must be completed. As with civil engineering, there is a long lead-in time before any construction begins on site. This is just as important with bioengineering and must be undertaken methodically. Table 4 shows the steps that need to be taken in most bioengineering projects.

Table 4: Planning, Design, and Implementation of Procedural Steps for Bioengineering

PHASE	STEP	ACTION TO BE TAKEN	RESULT/OUTPUT EXPECTED	LOCATION
Planning	1	Make an initial plan of the year's works	List of sites requiring treatment	Office
	2	Prioritize the work	List of sites in priority order	Roadline
	3	Initial site appraisal	Divide the sites into segments for assessment	Sites
	4	Assess the site	Detailed plan of site with problems identified	Sites
	5	Determine combination of works required	Initial plan of civil and bioengineering techniques	Sites
	6	Choose the optimal techniques for the site	List of techniques to be designed in detail, with measurements	Sites
Design	7	Design the civil and bioengineering works	Detailed designs for all required works	Office
	8	Select the species to use	List of actual species of plants to be used	Office
	9	Calculate the required quantities and rates	Table of quantities, rates, and costs for all required works	Office
	10	Finalize priority against available budget	Finalization of site works to be completed within available budget	Office
	11	Plan plant needs	Determination of the actual sources of bioengineering plants	Office
	12	Prepare documents and arrange implementation	Draft contract documents and arrange procurement	Office

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Table 4 continued

PHASE	STEP	ACTION TO BE TAKEN	RESULT/OUTPUT EXPECTED	LOCATION
Implementation	13	Prepare for plant propagation or procurement	Arrangements made for provision of all required plants	Nursery/Source
	14	Make the necessary site arrangements	Contracts and other procurement and logistical arrangements	Office/Sites
	15	Prepare the site for work	Site access and safety provisions completed	Sites
	16	Implement the civil engineering works	All earthworks and hard engineering completed	Sites
	17	Implement the bioengineering works	All bioengineering works completed	Sites
	18	Monitor the works	Regular inspections undertaken to ensure works are functioning	Sites
Maintenance	19	Maintain the works	Repairs, cleaning, and refinement undertaken, as necessary	Roadline/Sites

Sources: International Centre for Environmental Management. 2017. Slope Protection Designs and Specifications: Guidelines from Trials in Northern Viet Nam. ADB CDTA Project Promoting Climate Resilient Rural Infrastructure in Northern Viet Nam; and adapted from J. Howell, 1999. Roadside Bio-engineering: Site Handbook. Government of Nepal, Department of Roads: Kathmandu.

V. Bioengineering in ADB's Strategy 2030

The biggest contribution from bioengineering will be in its role in improving the reliability of infrastructure.

Strategy 2030 states that "ADB will promote quality infrastructure investments that are green, sustainable, resilient, and inclusive" and that "sustainable infrastructure investment will be central to achieving global commitments to address climate change and strengthen disaster risk management."

This is based on the definition provided in the ADB Annual Report 2017: "Sustainable infrastructure is infrastructure that is designed, built, and operated to be durable, socially equitable, and economically and environmentally viable."

Bioengineering's attributes of being low-cost, using traditional skills held by both women and men, being adaptable to most environments, contributing to ecosystems services, and being able to recover from damage mean that it is in itself green, sustainable, resilient, and inclusive.

Table 5 shows how bioengineering contributes to the operational priorities in ADB's Strategy 2030.

VI. Information Resources

Several guidance documents have been developed on the use of bioengineering in ADB member countries and elsewhere. Many of these have been elaborated in national highways sectors, but they have also emerged from rural development, irrigation, forestry, and soil conservation initiatives.

ADB has been instrumental in generating documentation, particularly in the Lao People's Democratic Republic, Viet Nam, and Timor-Leste. These guidance documents are usually based on project experience through the implementation of field trials or, in some cases, such as in Nepal, the mainstreaming of infrastructure works incorporating bioengineering. As a result, they are practical rather than academic in nature. They should be reviewed against the numerous conference papers on the subject, which refer to the use of bioengineering without providing the details needed to put it into practice.

The lack of continuity in technical approaches that are not mainstreamed or have drifted out of widespread use presents difficulties in finding appropriate reference materials. Even in the era of the internet, government agencies at the helm of various development initiatives fail to make their resources available.

Development partners and consultancy companies have high staff turnover rates and are also weak in providing the continuity that is needed. "Grey literature" is often not lodged in university collections.

Although information is often produced, it may not be easy to find. Diligent investigation at the national level during project preparation can reveal previous initiatives and materials, and this approach should always be considered best practice.

Table 5: Bioengineering in Relation to ADB's Strategy 2030

Operational Priorities	Approach in Strategy 2030	Contribution of Bioengineering
Addressing remaining poverty and reducing inequalities	"ADB's focus will include green and inclusive infrastructure..."	The use of local natural resources and skills, such as nursery work and planting, provide significant employment opportunities. Many of the required skills use traditional rural techniques, or adaptations of them, that are frequently possessed by women, or even solely by women in some societies.
Accelerating progress in gender equality	"Operations ... that incorporate ... actions in the design and implementation ... for instance, to increase employment opportunities for women during construction, operation, and maintenance."	
Tackling climate change, building climate and disaster resilience, and enhancing environmental sustainability	"Special consideration will be given to countries facing vulnerability because of geography such as hilly and mountainous conditions. These countries face acute problems due to changes in climate." "[ADB] will strengthen eco-sensitive project planning and design to prevent ecosystem degradation and mitigate pollution impacts. ADB will pursue this through a variety of approaches, including the use of payments for ecosystem services, nature-based solutions ..., and community-led approaches."	Bioengineering uses nature-based solutions almost exclusively. Since much of the work requires traditional rural skills, it can be done through community contracts or initiatives. Bioengineering measures require limited fossil fuel inputs, and living plants help to mitigate the drivers of climate change. The techniques have mostly been developed in hilly and mountainous environments, where they contribute greatly to soil protection and stability. The ability of bioengineering plants to recover from damage makes these systems very resilient.
Making cities more livable	"ADB projects will focus on addressing water security and environmental conservation."	Vegetation in cities helps provide shade and a pleasant recreational environment in public spaces. Bioengineering measures can contribute both to the reliability of upstream water supply catchments and to the control of runoff in cities.
Promoting rural development and food security	"ADB will focus on rural roads as part of improving market connectivity and agricultural value chain linkages."	Rural roads usually need to be low-cost and suited to the surroundings. In many cases, bioengineering is key to achieving this.
Strengthening governance and institutional capacity	"ADB will uphold environmental and social safeguards."	The use of bioengineering is often an environmental mitigation measure to protect exposed surfaces and reinstate disturbed land. Its application using labor-based methods can also make it valuable in upholding social safeguards.
Fostering regional cooperation and integration	In "promoting regional public goods, ADB will increase support for ... collective actions to mitigate cross-border risks pertaining to climate change, environmental pollution, [etc.], through regional cooperation in areas such as disaster risk financing, watershed development [etc.]"	While bioengineering's application is at the field and site scale, its extensive use helps to protect watersheds and mitigate the drivers of climate change. Its ecosystems services and socioeconomic contributions mean that benefits extend beyond its immediate engineering functions.

Source: J. Howell.

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Bioengineering for Green Infrastructure

This awareness-raising material is intended to inform those involved in the design and implementation of the Asian Development Bank's investment projects of the advantages of bioengineering. It describes the issues that need to be considered for the successful application of bioengineering.

- Bioengineering refers to the use of vegetation to serve an engineering function, forming a practical subset of green infrastructure.
- Aside from serving its primary engineering purposes, bioengineering provides socioeconomic and ecosystem services.
- Bioengineering has been applied to infrastructure in countries throughout Asia and the Pacific, and it has the potential for greater use in a wider scope.
- The techniques in bioengineering fit well with the Asian Development Bank's Strategy 2030 and contribute to various degrees to all the operational priorities.

About the Asian Development Bank

ADB is committed to achieving a prosperous, inclusive, resilient, and sustainable Asia and the Pacific, while sustaining its efforts to eradicate extreme poverty. Established in 1966, it is owned by 68 members —49 from the region. Its main instruments for helping its developing member countries are policy dialogue, loans, equity investments, guarantees, grants, and technical assistance.